Documentation on Calibration and Validation of CEAP-HUMUS for various River Basins in the United States

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This document describes the calibration-validation procedure used in the CEAP project for cultivated cropland. It covers SWAT-HUMUS and APEX model calibration procedures for simulation of flow, sediment, nitrogen, phosphorus and Atrazine. The document is arranged as follows: Chapter 1 covers the detailed calibration procedure and the results of Upper Mississippi River basin. The remaining chapters further describe model calibration-validation results for other river basins in the order of completion.

Table of Contents

Chapter 1

Calibration and Validation of CEAP-HUMUS and their Implementation for the Upper Mississippi River Basin

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Chapter 1 describes results of calibration and validation of CEAP-HUMUS model setup for the Upper Mississippi River Basin. This chapter contains the procedures used in the calibration-validation process along with the necessary examples.

(Status: Complete)

The SWAT- HUMUS modeling setup quantifies the offsite environmental benefits obtained from the conservation practices implemented on cropland in the United States. To perform this task, reasonably accurate estimates of water runoff and material transfer via both surface and subsurface pathways are required. In addition to matching predicted and observed runoff, it is essential to partition simulated runoff correctly into different hydrological pathways such as surface runoff and subsurface flow, or base flow. This requires a robust procedure to calibrate runoff/water yield as well as partition runoff into surface runoff and subsurface flow.

At the 8-digit watershed level, two simulation models—APEX for cultivated areas and SWAT for other land uses, were run independently. Since the APEX simulation results are for cultivated land only, the average flow from both cultivated and non-cultivated land (simulated by SWAT) for the 8-digit watershed is not known when APEX is running. Therefore, the water yield calibrations of APEX for the cultivated portion of the watershed and of SWAT for the non-cultivated portion are required so that the water yields from cultivated areas would be reasonable when HUMUS/SWAT stream flow is compared to observed stream flow. Because cultivated area estimates are made via a sampling and modeling approach; simulated water yields are aggregated to the 8-digit watershed level using the statistical sampling weights derived from the National Resource Inventory (NRI) data. Therefore, the calibration procedure is different for cultivated land as compared to other land uses. This chapter discusses calibrations of APEX and HUMUS/SWAT for the Upper Mississippi River Basin and validation of the CEAP modeling framework at selected gauging stations.

Flow calibration and validation procedure

The APEX and HUMUS/SWAT system was run with weather data from 1960 through 2006 (47 years) to represent long-term weather conditions in the Upper Mississippi River Basin (UMRB) (Figure 1-1). For the purpose of the CEAP national assessment, the APEX and SWAT models were calibrated with 30 years of data (1961-90) and validated with 16 years of data (1991-2006) before scenario trials. Average annual runoff from each 8-digit watershed was used for spatial calibration. Monthly and annual average stream flows at selected gauging stations along the Mississippi River were used for temporal calibration and validation. Model outputs from the current conditions scenario were used for calibration and validation. Calibration of average annual runoff helps ensure local water balance at the 8-digit watershed level. The temporal calibration and validation (annual and monthly) is performed to ensure annual and seasonal variability.

Calibration of average annual runoff at 8-digit watersheds

At the 8-digit watershed level the two models were run independently. The simulated average annual water yield by each model was calibrated separately against the observed runoff estimated from the USGS runoff contours (Gebert et al., 1987). The results from APEX represent the average annual values from only the cultivated areas at each 8-digit watershed; the results from SWAT represent the average annual values from all other land uses. The observed runoff was the average annual value from all land uses.

The criteria for APEX calibration was based on the percentage of cultivated land at each 8-digit watershed (Table 1-1). The criteria for SWAT calibration was set to the simulated average annual water yields within 20 percent of the observed values. This ensures good agreement on contribution of annual runoff spatially across 8-digit watersheds.

Calibration of APEX

Figure 1-2a shows the calibration procedure, which demonstrates how the average annual water yield calibration is carried for 8-digit watersheds. Four parameters were used for APEX water yield calibration (Table 1-2). The soil water depletion coefficient adjusts surface runoff and subsurface flow in accordance with soil water depletion (Kannan et al., 2006). The Hargreaves PET equation exponent is a coefficient used to adjust evapotranspiration (ET) estimated by the Hargreaves method (Hargreaves and Samani 1985) and water yield. The return flow ratio is the ratio of return flow to channel and the total percolation flow. The tile drainage saturated hydraulic conductivity coefficient controls the upper limit of tile drain flow. The adjustable ranges of these parameters (Table 1-2) were based on the APEX user manual (Williams et al., 2003), literature reported ranges (Wang et al., 2006), and expert knowledge from the model developer, Jimmy Williams.

Calibration of SWAT

An automated calibration procedure (Kannan et al., 2008) uses nine parameters to calibrate average annual water yield or total runoff, surface runoff, and subsurface flow. If necessary, the procedure uses a linear interpolation method to obtain a better value of a model parameter. The calibration process is carried out in three major steps: (1) adjustment of water yield, (2) surface runoff, and (3) subsurface runoff.

Figures 1-2b and 1-2c show the automated calibration procedure, which demonstrate in detail how the average water yield calibration is carried out for the 8-digit watersheds.

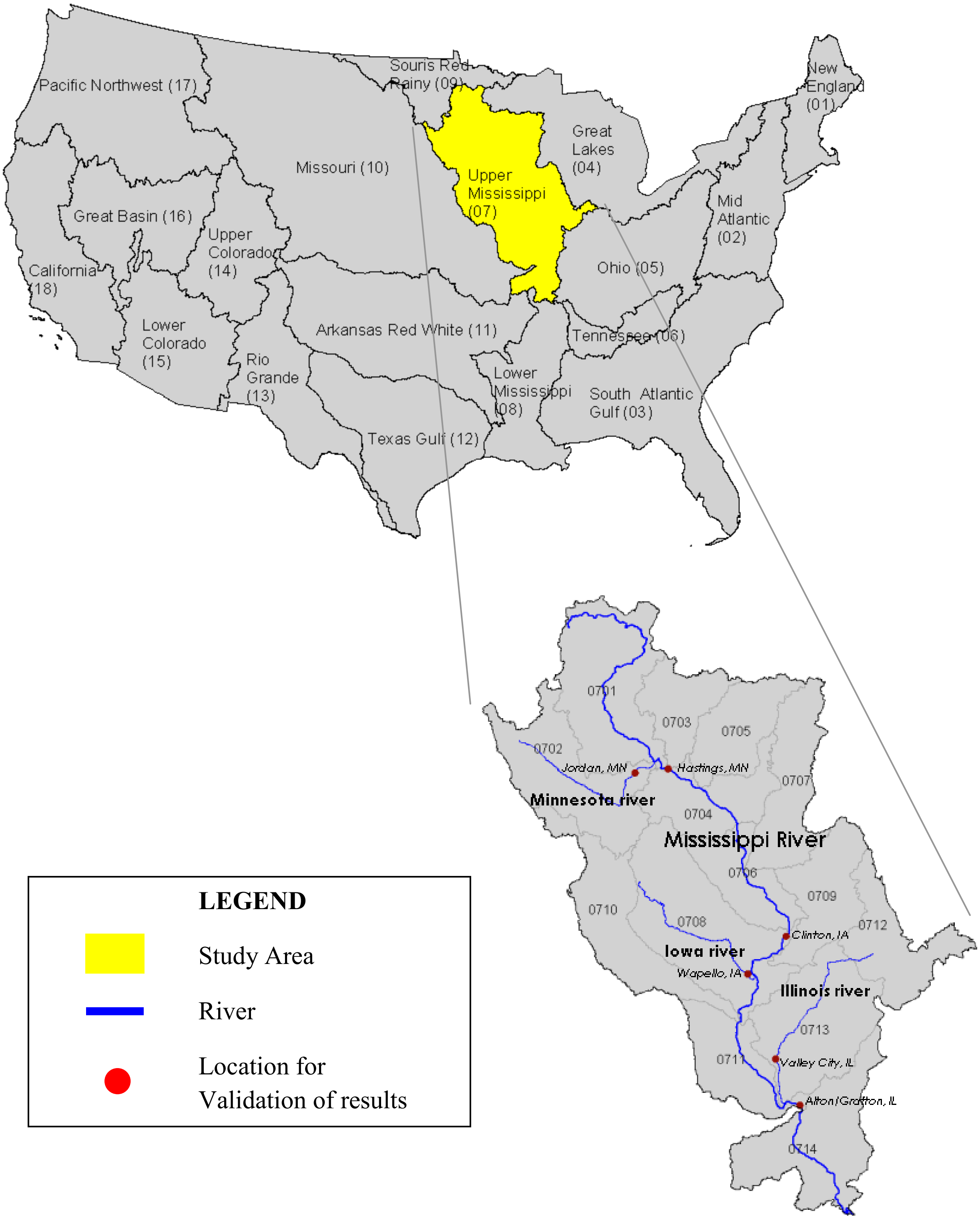


Figure 1-1 Location of the Upper Mississippi River Basin and sampling locations

Table 1-1 Criteria for APEX water yield calibration at the 8-digit watershed level

% (Cultivated+CRP) Area water yields	% difference between APEX and USGS annual average
<10	within 50
10-20	within 45
20-30	within 40
30-40	within 35
40-50	within 30
50-60	within 25
60 & above	within 20

Table 1-2 Parameters used in the APEX calibration procedure, their range, and their effect on different components of runoff

Parameter	Changes			Range Used	
	Surface Runoff	Sub-Surface Runoff	Water Yield	Minimum	Maximum
Depletion Coefficient	x	x	x	0.5	1.50
Hargreaves PET Equation Exponent	x	x	x	0.5	0.6
Return Flow Ratio	x		x	0.05	0.95
Tile Drainage Saturated Hydraulic Conductivity Coefficient	Tile Drain Flow		x	0.8	3.0

Observed/estimated data used for spatial calibration

Observed/targeted water yield

The target values for calibration are based on runoff contours for the nation prepared by Gebert et al. (1987). The source of information for the runoff contours was stream flow recorded from 5951 USGS gauging stations during 1951-1980 with an area not exceeding an 8-digit watershed. The runoff contour data reflects the runoff of tributary streams so that small-scale variations in runoff are represented with reasonable accuracy. Annual average water yield by HUC or 8-digit watershed is obtained by overlaying interpolated runoff contours representing average annual runoff (in inches) for the conterminous United States with the HUC map. The resulting annual average runoff values are used as target values for calibrating the predicted annual average water yield from HUMUS-SWAT.

Observed/targeted subsurface flow

Arnold et al. (2000) developed a digital filter technique to partition the stream flow between surface runoff and base flow. In this technique, the base flow ratio is the ratio of sub- surface flow to total flow. To estimate subsurface flow, the ratio is multiplied by the observed water yield. Santhi et al. (2008) have estimated the base flow (subsurface flow) ratio for all the 8-digit watersheds in the United States using the digital filter technique. To obtain subsurface flow for an 8-digit watershed in a river basin, the base flow ratio should be multiplied with the corresponding water yield for the 8-digit watershed. The difference between water yield and subsurface flow is used as surface runoff. The data obtained this way are used as observations/target values to calibrate runoff/water yield, subsurface flow, and surface runoff.

Annual and monthly flow calibration and validation at stream gages

Five USGS stream gages were selected in the UMRB for annual and monthly flow calibration and validation (all gauges shown in Figure 1-1, except Hastings, MN, which had very limited flow data). Calibration was performed for the period 1961 to 1990 to ensure that there was a reasonable agreement between predicted and observed flow at annual and monthly time steps. The model was validated for annual and monthly flows in the same stream gages for the period 1991 to 2006 without changing the calibrated input parameters.

Evaluation criteria for annual and monthly flow calibration

Statistical measures such as mean, standard deviation, coefficient of determination (R^2), and Nash-Sutcliffe prediction efficiency (NSE) (Nash and Sutcliffe 1970) were used to evaluate the annual and monthly simulated flows against the measured flows at the gages. If the R^2 and NSE values were less than or very close to zero, the model prediction is considered "unacceptable or poor." If the values are 1.0, then the model prediction is "perfect." Values greater than 0.6 for R^2 and greater than 0.5 for NSE were considered "acceptable" (Santhi et al., 2001; Moriasi et al., 2007).

Demonstration of the SWAT automated flow calibration procedures

The automated calibration procedure spatially calibrates the following HUMUS-SWAT model parameters so that the simulated average annual water yield, sub-surface flow and surface runoff match the corresponding target values for each USGS 8-digit watershed (Kannan et al., 2008) in the river basin. The calibration goals are to keep the differences between simulated and target values within 10 percent for surface runoff, 10 percent for subsurface flow, and 20 percent for water yield.

- HARG_PETCO, a coefficient used to adjust potential evapotranspiration (PET) estimated by the Hargreaves method (Hargreaves and Samani 1985; Hargreaves and Allen 2003) and calibrate the runoff/water yield in each 8-digit watershed. In the Hargreaves method, PET is related to temperature and terrestrial radiation. This coefficient is related to radiation and can be varied to account for the differences in PET in different parts of the river basin depending on weather conditions (Hargreaves and Allen 2003).
- Soil water depletion coefficient (CN_COEF), a coefficient used in the curve number method to adjust the antecedent moisture conditions on surface runoff generation.
- Curve Number (CN), used to adjust surface runoff and relates to soil, land use, and hydrologic condition at the HRU level.
- Groundwater re-evaporation coefficient (GWREVAP) controls the upward movement of water from shallow aquifer to root zone due to water deficiencies in proportion to potential evapotranspiration. This parameter can be varied depending on the land use/crop. The re-evaporation process is significant in areas where deep-rooted plants are growing and affects the groundwater and the water balance.
- GWQMN—Minimum threshold depth of water in the shallow aquifer to be maintained for groundwater flow to occur to the main channel.
- Soil available water-holding capacity (AWC), which varies by soil at HRU level.
- Soil evaporation compensation factor (ESCO), which controls the depth distribution of water in soil layers to meet soil evaporative demand. This parameter varies by soil at the HRU level.
- Plant evaporation compensation factor (EPCO), which allows water from lower soil layers to meet the potential water uptake in upper soil layers and varies by soil at the HRU level.

The above input parameters were adjusted within literature reported ranges for the SWAT model (Neitsch et al., 2002; Santhi et al., 2001), and expert knowledge from the SWAT model developer Jeff Arnold.

Table 1-3 demonstrates the auto-calibration procedure using the 8-digit watershed 07020008 of the UMRB for the non-cultivated area. The table shows that the difference between predicted and target water yield at the beginning is within the stipulated value (4.2 percent existing vs. 20 percent target). Therefore, HARG_PETCO was not parameterized to adjust the water yield. However, the percent difference between predicted and observed annual average surface runoff is beyond the threshold (-54 percent existing vs. 10 percent threshold), indicating underestimation of surface runoff. Therefore, the depletion coefficient is adjusted to bring predicted surface runoff to within 10 percent of the target value. In doing so, the underestimation (before depletion coefficient parameterization) has changed to overestimation (after depletion coefficient parameterization). Hence, a linear interpolation was performed to identify the suitable value for depletion coefficient that keeps the predicted surface runoff within 10 percent of target value. After the adjustment of depletion coefficient, the percent difference between predictions and observations of annual average surface runoff is 1.9 (within the target/benchmark) eliminating the need for further adjustment of surface runoff using CN.

Figure 1-2a APEX calibration procedure for water yield from cultivated land aggregated at the 8-digit watershed level

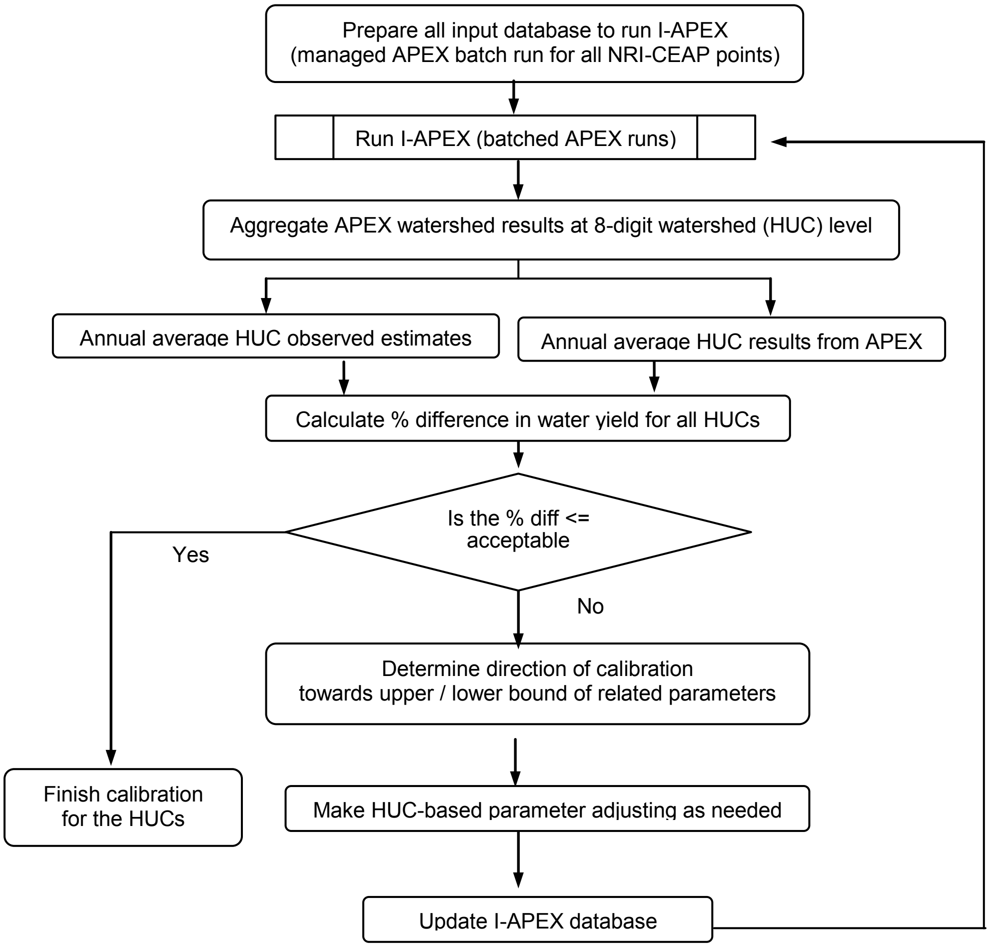


Table 1-3 Demonstration of auto-calibration procedure for HUMUS-SWAT using an 8-digit watershed (7020008) in the Upper Mississippi River Basin

Parameter	Adjustment/ interpolation	% Difference between predictions and observations			Surface runoff (mm)	Subsurface runoff (mm)	Water yield (mm)
		Surface runoff	Subsurface flow	Water yield			
No calibration	None	-54.0	68.4	4.2	20.39	67.52	87.92
harg_petco	None	-54.0	68.4	4.2	20.39	67.52	87.92
depletion co-efficient	Adjusted	17.5	8.2	13.1	52.03	43.38	95.41
depletion co-efficient	Interpolated	1.9	20.6	10.8	45.13	48.37	93.51
curve number	None	1.9	20.6	10.8	45.13	48.37	93.51
GWREVAP	Adjusted	1.9	19.6	10.3	45.13	47.95	93.08
GWQMN	Adjusted	1.9	-79.9	-37.0	45.13	8.05	53.18
GWQMN	Interpolated	1.9	13.3	7.3	45.13	45.42	90.55
AWC	Adjusted	1.9	13.3	7.3	45.13	45.42	90.55
Slope length	Adjusted	1.9	13.2	7.3	45.13	45.39	90.53
EPCO	Adjusted	1.9	13.3	7.3	45.13	45.43	90.56
ESCO	Adjusted	1.1	-58.4	-27.2	44.78	16.70	61.48
ESCO	Interpolated	1.8	-7.4	-2.6	45.10	37.14	82.24
Observed/Estimated	Not applicable				44.30	40.10	84.40

Figure 1-2b Automated calibration procedure-Determination of 8-digit watersheds to be calibrated

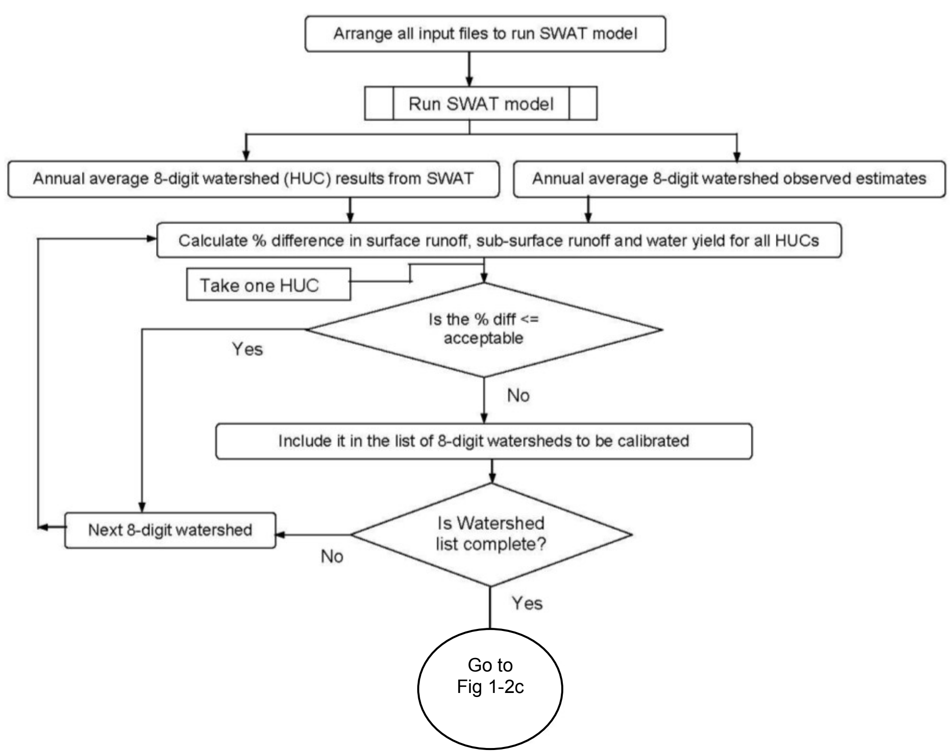
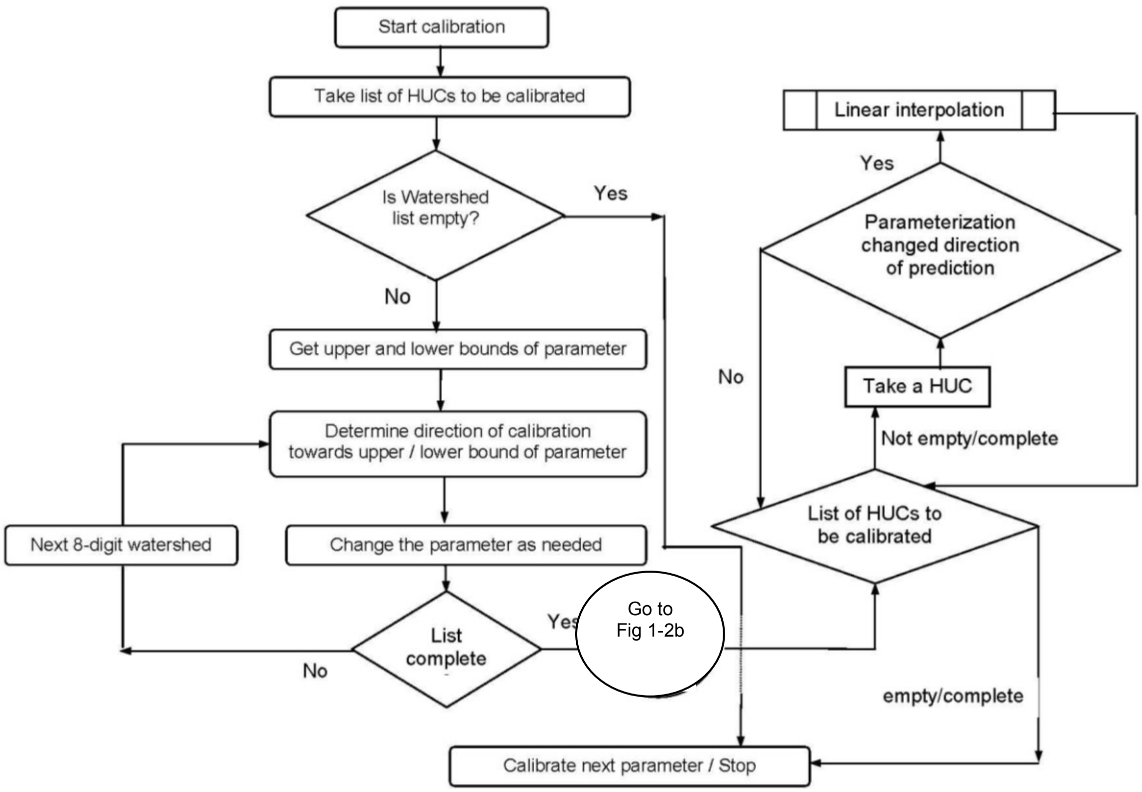


Figure 1-2c Adjustment and interpolation of parameters



Although the predicted water yield is still within 20 percent of observation (after adjustment of depletion coefficient), the subsurface flow is not within the target value of 10 percent. Therefore, subsurface flow was adjusted using appropriate parameters. After the parameterization of GWREVAP, GWQMN, slope length, EPCO, and ESCO, respectively, the predicted annual average subsurface flow for HUC 07020008 is brought within 10 percent of target. In Table 1-3, the predicted values for surface runoff, subsurface flow, and water yield and the percent difference between predictions and target are shown at every step of calibration for better understanding of the automated calibration procedure.

The performance of the automated calibration procedure is analyzed considering the entire UMRB (cultivated and non-cultivated area). Figure 1-4, showing percent difference between predicted and target values of annual average water yield for entire UMRB, implies that the quality of calibrated (predicted) annual average water yield is good. Means and standard deviations of predicted and target annual average water yields of all the HUCs in the river basin also support the conclusion (Table 1-4). Performance evaluation of the model after calibration using Nash and Sutcliffe prediction efficiency and R^2 are given in Figure 1-3, which shows that the prediction efficiency is acceptable after calibration. In addition, the number of HUCs outside the calibration targets decreased appreciably after calibration (Figure 1-4).

Calibration results of the average annual runoff at 8-digit watersheds

Average annual water yield from cultivated and non-cultivated land

The average annual simulated and targeted runoff of the 8-digit watersheds in the Upper Mississippi River Basin is shown in Figure 1-4. Targeted and simulated runoff patterns concur with the precipitation patterns of this basin. The regression relationship between targeted and simulated runoff at 8-digit watersheds (R^2 is 0.86) and the means and standard deviations of annual runoff (of all the 8-digit watersheds in the river basin) indicate that the model prediction is satisfactory (Figure 1-4 and Table 1-4).

Annual and monthly flow calibration and validation at stream gages

Flow calibration and validation results at annual and monthly time steps are shown in Figures 1-5 to 1-8 and Tables 1-5 to 1-8 for the stream gages located in Minnesota river (Jordan, MN), Iowa river (Wapello, IA), Illinois river (Valley City, IL) and Mississippi River (Clinton, IA and Alton/Grafton, IL and Thebes, IL).

Observed and simulated flows at annual and monthly time steps matched very well for the calibration period (Figures 1-5 and 1-6). Means and standard deviations of predictions and observations are in close agreement (Table 1-5). In addition, the coefficient of determination is greater than 0.6 (R^2) and NSE is greater than 0.5 (Tables 1-6) for all the gauges except Thebes, IL during the calibration period. In summary, the model performance evaluation measures suggest an overall good agreement between observed and simulated flows at the annual and monthly time step, throughout the river basin.

Annual and monthly flow results for the above listed gauging stations for validation period are shown in (Figures 1-7 and 1-8 and Tables 1-7 and 1-8). Based on R^2 and NSE it can be seen that almost all the gauges show acceptable predicted results from model. In summary, HUMUS-SWAT is able to capture the annual and monthly flow patterns very well in the Upper Mississippi River basin.

Calibration/validation of sediment, nutrient, and pesticide concentration at the USGS gauging stations

Sediment and nutrient (various forms of nitrogen and phosphorus) calibration was a challenging task. Similar to flow, water-quality data were not available at the 8-digit watershed (spatial) scale. Continuous data from the gauging stations selected for validation were also not available for sediments, nutrients, and pesticides; therefore, the regular split sample procedure for calibration and validation was not done because of limited availability of data. Instead, the entire set of available water quality loads were used to validate the quality of model predictions for each water quality parameter (e.g. ammonia-nitrogen validation).

Limited water quality data available from USGS under their regular monitoring program and a special program (NASQAN) were used for validation of predicted results from the UMRB. Grab samples of monitored data of suspended sediment, and atrazine were available from USGS for selected gauging stations in the UMRB. Typically there were 10-20 samples per year available for a few years. These grab-sample concentrations, along with observed daily flow (because instantaneous flow is not available for all the corresponding water quality grab samples) is taken to a load estimator program (Runkel et al., 2004) to get annual average loads of suspended sediment and atrazine. Uncertainty limits were estimated by the program whenever there were enough samples.

The NASQAN data set provides monthly and annual average nutrient loads with uncertainty limits wherever possible. For this dataset, nutrient fluxes were estimated using an adjusted maximum likelihood estimate, a type of regression-model method and a composite method using various components of nutrient observations (nitrate-nitrogen, ammonia-nitrogen, orthophosphate, etc.)

monitored from 1960 through 2005 (Aulenbach et al., 2007). Nutrient flux estimates are provided for six water-quality constituents: dissolved nitrite plus nitrate, total organic nitrogen plus ammonia-nitrogen (total Kjeldahl nitrogen), dissolved ammonia, total phosphorous, dissolved orthophosphate, and dissolved silica. For this study, reported annual loads (of water years) from NASQAN were not used. Instead, the annual loads for calendar years were aggregated from monthly loads.

Simulated annual average pollutant loads corresponding to the years of available observed/estimated calibration target loads were used to validate the water quality predictions from model. Wherever possible, uncertainty limits of observations/estimated targets for calibration were presented to make reasonable judgments on model predictive capability. For all the gauging stations selected for validation, the predicted pollutant loads were compared against the observed/estimated targets using graphs with error bars. To limit the content of this chapter, graphs for only three (out of six) stations were presented. Comparison of annual predicted and target means were presented for all the water quality parameters in tables.

In the UMRB, a major portion of the river basin is cultivated; therefore, water-quality validation relies heavily on APEX's results. For cultivated land, after making sure that the fertilizer/manure rates and nutrient dynamics are reasonable, limited need-based parameter adjustment is performed based on over or under-estimation of predicted results when compared to observed data. Delivery ratios were used for transport of sediment, nutrient and pesticides from edge-of-field to the 8-digit watershed outlet. Water quality calibration/validation for HUMUS-SWAT is described in the following sections.

Sediment calibration in HUMUS-SWAT

For calibration of sediment yield simulated for non-cultivated land use in each 8-digit watershed, some of the soil erosion and sediment-related parameters within SWAT were adjusted. The soil-erodibility factor (K) was adjusted when there was under/over-prediction of sediment. The delivery ratio that accounts for losses occurring from the fields to the 8-digit watershed outlet was adjusted.

The instream sediment-related parameters such as SPCON and SPEXP within SWAT were adjusted for the channel losses to be realistic. SWAT uses the modified Bagnold stream power equation for channel sediment routing (Arnold et al., 1995; Neitsch et al., 2002). In this equation, the maximum amount of sediment that can be transported by water from a reach segment is related to the peak channel velocity estimated for each 8-digit channel reach using a linear parameter (SPCON) and exponential parameter (SPEXP). SPCON is the linear parameter used for calculating the maximum amount of sediment that can be re-entrained during channel sediment routing. It is a user-defined coefficient and varies between 0.0001 and 0.03. For the CEAP national assessment for the UMRB, SPCON was set to 0.03. SPEXP is an exponent parameter used for calculating the maximum amount of sediment that can be re-entrained during channel sediment routing. It can vary between 1.0 and 2.0. For the UMRB, SPEXP was set at 1.0. These two parameters were calibrated to match the observed sediment load at selected gauging stations for validation. In addition, the sediment routing process was modified considering the cumulative drainage area and an exponential coefficient at main reach along the Upper Mississippi River to account for channel losses to be realistic for the CEAP National Assessment (Barry et al., 2005).

Predicted sediment results were validated in six different gauging stations (Fig 1-1) in the UMRB as outlined in Table 1-9. To limit the contents of this section, detailed results are shown only for three locations. However, the means are shown for all stations (Table 1-9). Figure 1-9 shows a detailed comparison of predicted and target sediment loads in Mississippi River at Clinton, IA, Illinois River at Valley City, IL and Mississippi River at Alton/Grafton, IL. In general, there is under-estimation (Table 1-9, Figure 1-9) of annual sediment load in different locations (except Alton, IL). For gauges in Valley City, IL and Grafton/Alton, IL there is close match between predictions and target values of sediment load (Figure 1-9). In other places, the predicted loads are within an order of magnitude from the target values. Uncertainty limits were not available to make any further judgment on the quality of predicted results. However, considering the quality of predicted sediment loads in all the places of validation, we could say the model results are adequate for making scenario trials.

Nutrient calibration

Whenever there is over or under-estimation of nutrients, the first item checked is the rate of application of fertilizer/manure for the crops and pasture/hay. The second item checked is the nutrient dynamics and partitioning of applied nutrients (i.e. transformation between different pools of N and P such as mineral, organic, soluble, sediment bound etc.). If the above two are reasonable and still there is a mismatch between predictions and target values, then parameterization is attempted.

Nitrogen calibration in HUMUS-SWAT

For non-cultivated land once the rates and nutrient dynamics are reasonable, upland parameters (basin level) such as nitrogen uptake distribution parameter (UBN) and nitrogen percolation coefficient (NPERCO) were adjusted to match the predicted nutrient load with that of target. UBN changes the crop uptake of applied nitrogen and NPERCO changes the proportion of soluble N available for surface runoff and leaching. If the mismatch still exists then the in-stream nutrient sensitive parameters were adjusted (e.g. for nitrogen it is Hydrolysis rate constant (BC3) of nitrogen (N to NH_4)).

Phosphorus calibration in HUMUS-SWAT

The basin level parameters adjusted are phosphorus uptake distribution parameter (UBP), phosphorus percolation coefficient (PPERCO) and phosphorus soil partitioning coefficient (PHOSKD). In the model they affect plant uptake of applied phosphorus, proportion of soluble P available for surface runoff and leaching and partitioning of phosphorus between soluble and sediment bound phases. The in-stream phosphorus parameters attempted are 1. Mineralization rate (BC4) of organic phosphorus (organic P to Soluble P) and 2. Benthic source rate (RS2) for soluble P in the reach.

Predicted nutrient results were validated in seven gauging stations (Figure 1-1) in the UMRB as outlined in Table 1-10, and Table 1-11. To limit the contents of this section, detailed results are shown for three locations only. The predicted and target means are shown for all the six stations (Table 1-10 and Table 1-11). Figures 1-10 through 1-14 depict a detailed comparison of predicted and target nutrient loads (various constituents of N and P) in Mississippi River at Clinton, IA, Illinois river at Valley City, IL and Mississippi River at Alton/Grafton, IL. Error bars or the upper and lower confidence levels of target values are also presented. In general, the predicted nutrient loads from HUMUS-SWAT are in good agreement with the target values and within the uncertainty limits of target values for a majority of the nutrient constituent-location combination suggesting the suitability of the model for making scenario trials.

Pesticide calibration in HUMUS-SWAT

Similar to sediment, only limited grab sample data was available for calibration of pesticides. It is very likely that many different pesticides were applied to crop and non-crop areas in the river basin. However, for this UMRB study, only the fate and transport of atrazine is considered. The only source of atrazine load is cultivated land; point sources and non-cultivated land had no atrazine contributions. Therefore, here again the overall quality of predicted atrazine results depend on APEX results for cultivated land. After incorporating APEX output, if there is a mismatch between predictions and target values, in-stream pesticide parameters such as pesticide reaction coefficient in reach (CHPST_REA) (function of pesticide aquatic half-life), Pesticide water/sediment partitioning coefficient were attempted to improve the model predictions.

Predicted atrazine results were validated in four gauging stations in the UMRB as outlined in Table 1-12, Figure 1-15. To limit the contents of this chapter, detailed results are shown for three locations only. However, the predicted and target annual means are shown for all the four stations (Table 1-12). Figure 1-15 show a detailed comparison of predicted and target atrazine loads in Mississippi River at Clinton, IA, Illinois River at Valley City, IL and Mississippi River at Alton/Grafton, IL. In general, the pattern/trend of predicted atrazine loads from HUMUS-SWAT is in agreement with the target values for all the gauges selected for validation except Clinton, IA. The under-estimation can be attributed to uncertainties in observations, procedure used to obtain annual loads from daily grab samples, model input in particular the management operations, inadequate accounting some of the possible sources etc. Within the limited time given for calibration, it was only possible to check the rates, proportion of constituents (soluble vs. sorbed) etc. Further investigation into the above mentioned items could have improved our estimates. The same reasons could be attributed to the few mismatches in sediment and nutrient loads.

In this study, two models, APEX and SWAT were used for modeling cultivated and non-cultivated land respectively. Therefore, the calibration/validation process involves many back and forth efforts. First the APEX model is calibrated, and then SWAT. After verifying the instream flow and pollutant loads feedback was given to APEX or HUMUS-SWAT team depending on the possible source of problems in cultivated/non-cultivated land. After identifying the source of problems, the necessary remedial measures were attempted.

Table 1-4 Basin-average statistics for predicted and target annual water yield for all 8-digit watersheds in the UMRB—Combined water yield results from APEX and SWAT after calibration (1961–90)

Calibration	Statistic	Value
Predictions (After calibration)	Mean (mm)	225.4
	Standard deviation (mm)	66.8
Observations	Mean (mm)	203.1
	Standard deviation (mm)	66.4

Figure 1-3 Average annual water yield of all 8-digit watersheds in the Upper Mississippi River Basin from cultivated and non-cultivated area (combined water yield from APEX and SWAT)

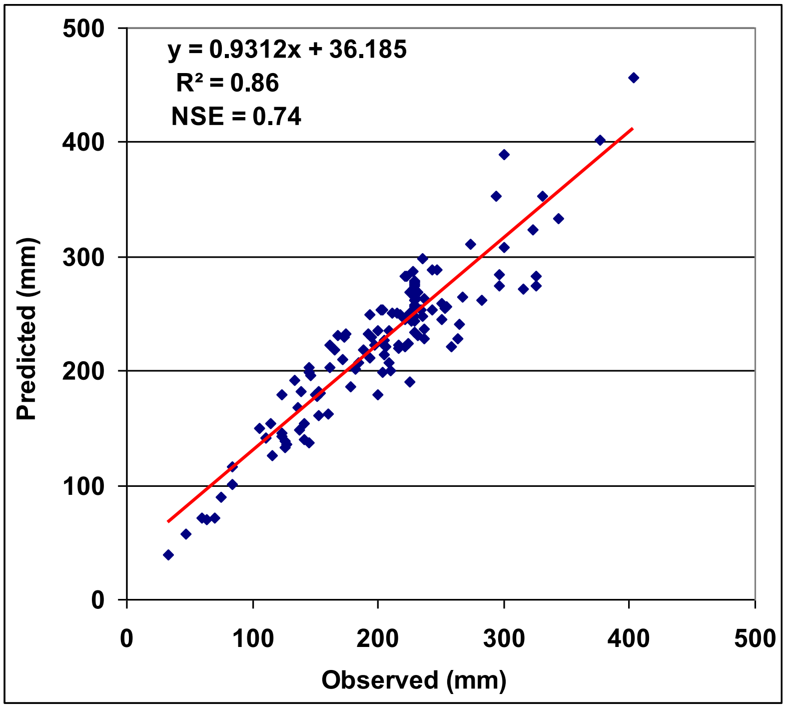


Figure 1-4 Percentage difference between predictions and observations of annual average flow in the UMRB (combined water yield from APEX and SWAT after calibration

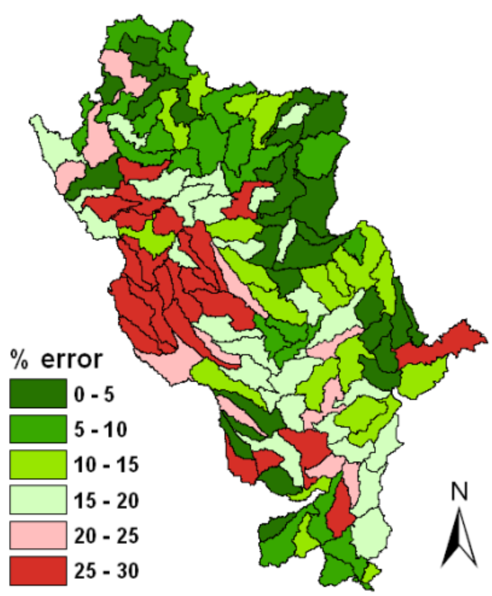
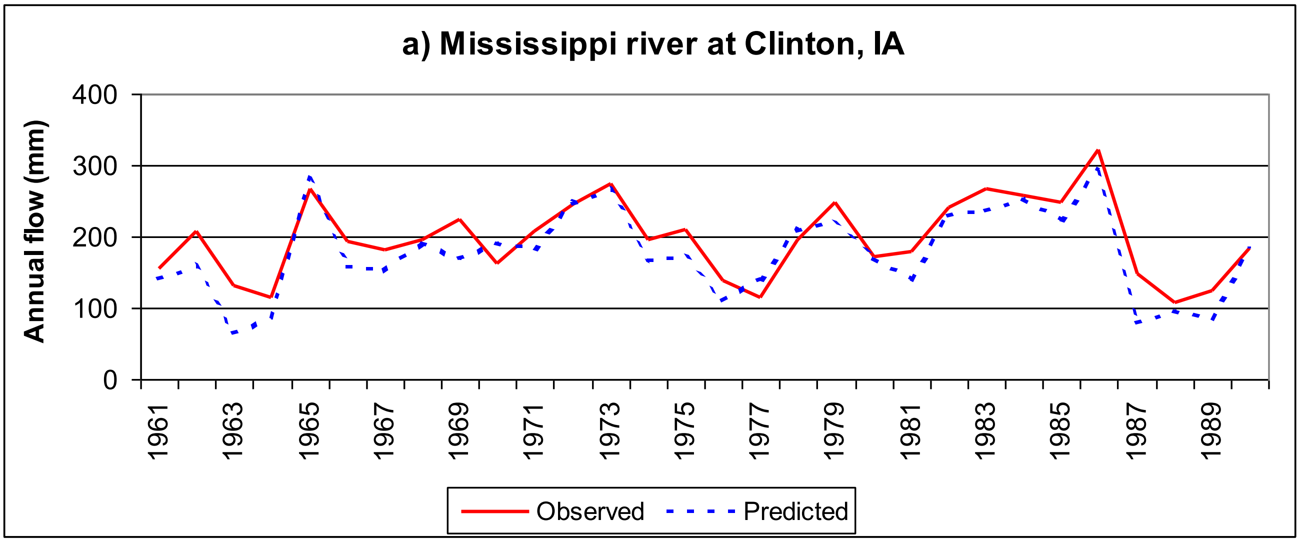
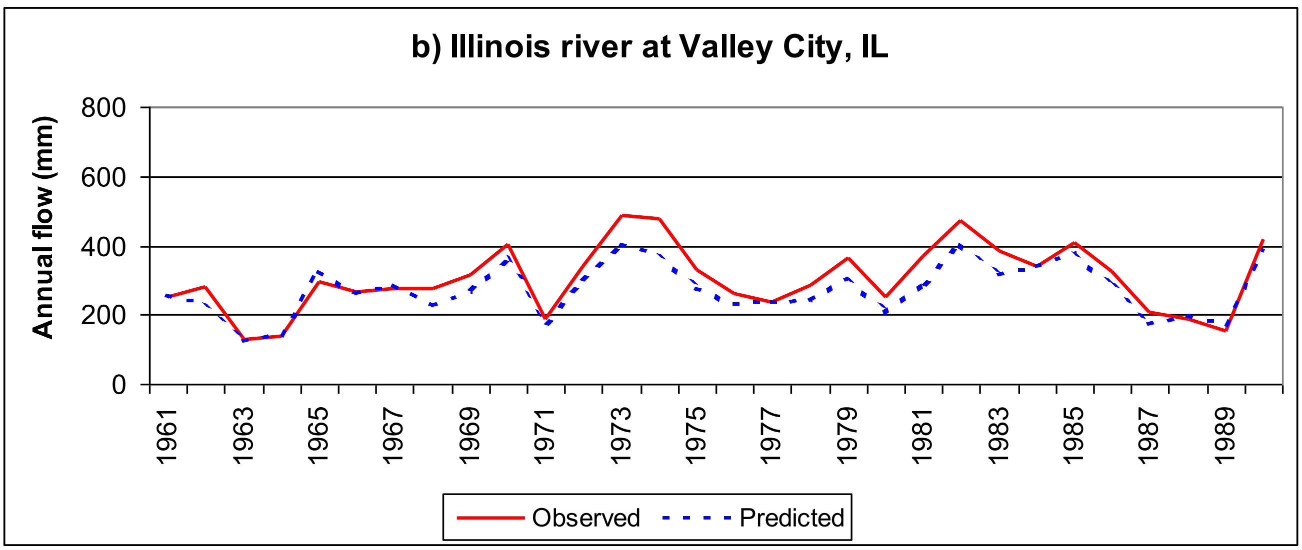


Figure 1-5 Average annual stream flow for the Upper Mississippi River basin-Calibration period





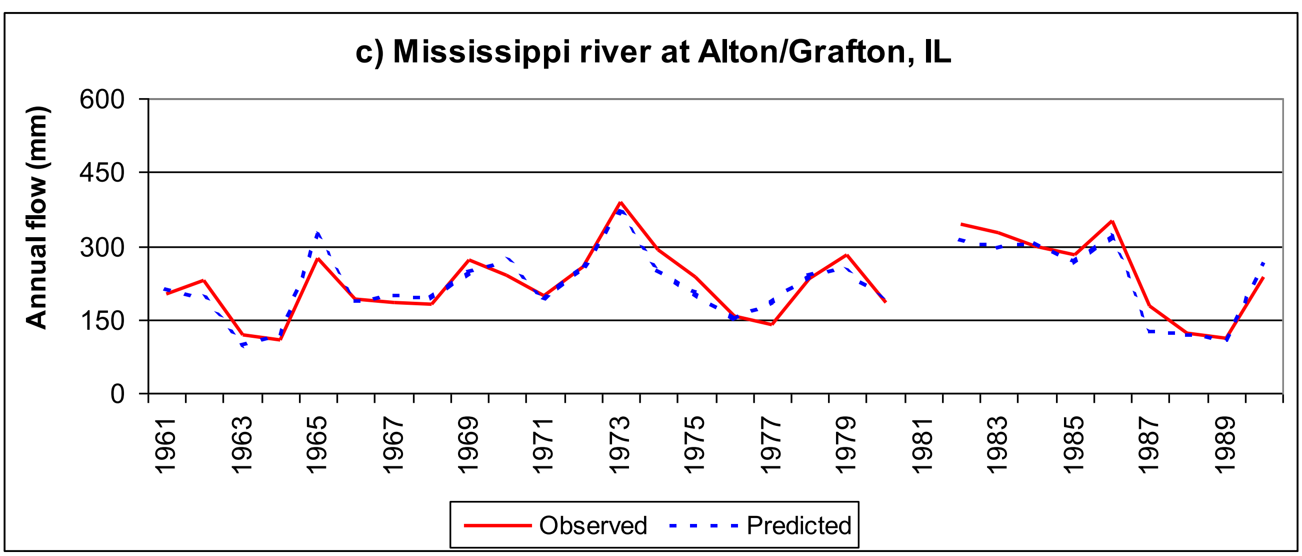


Figure 1-6 Average monthly stream flow for the Upper Mississippi River basin-Calibration period

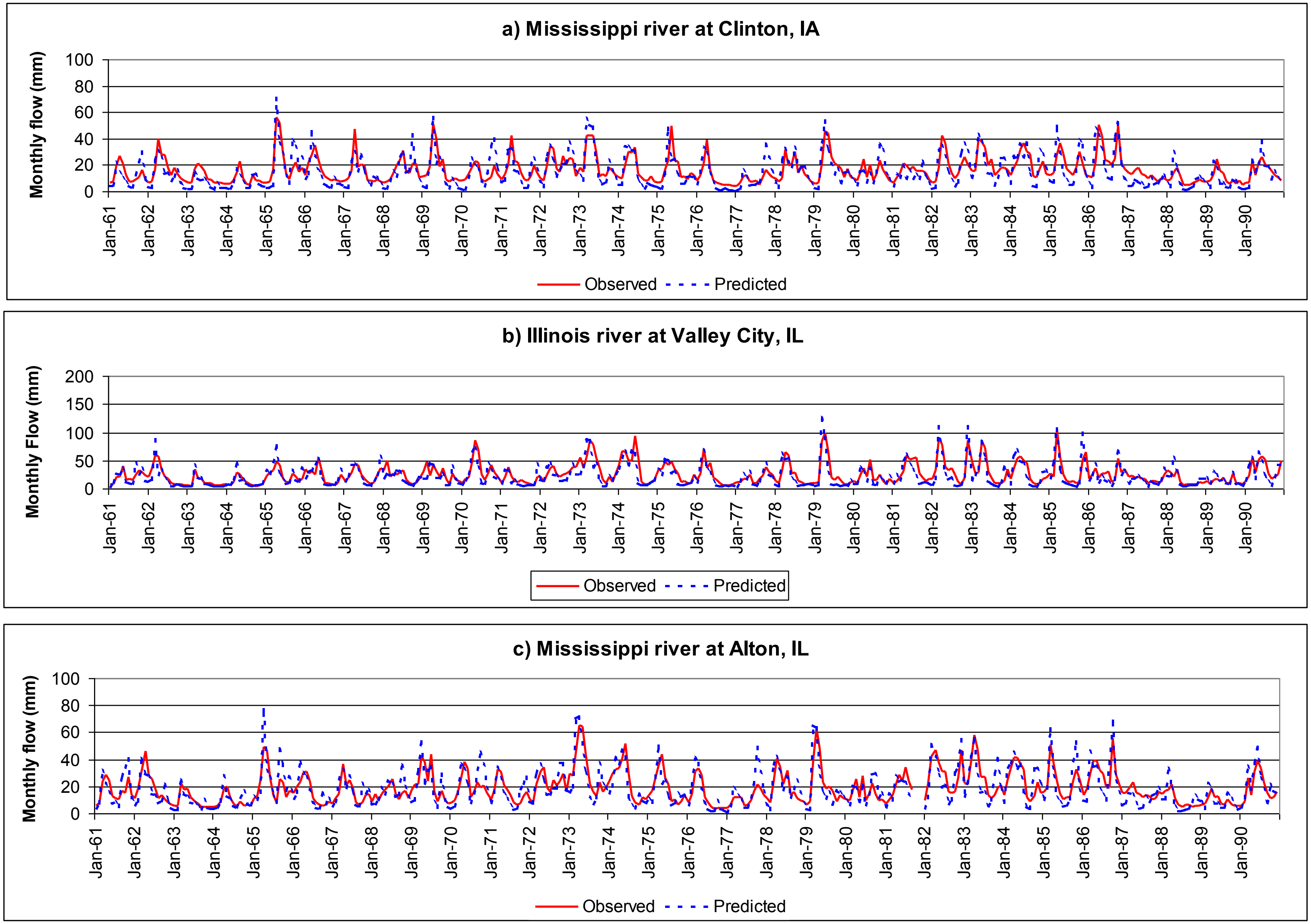


Figure 1-7 Average annual stream flow for the Upper Mississippi River basin-Validation period

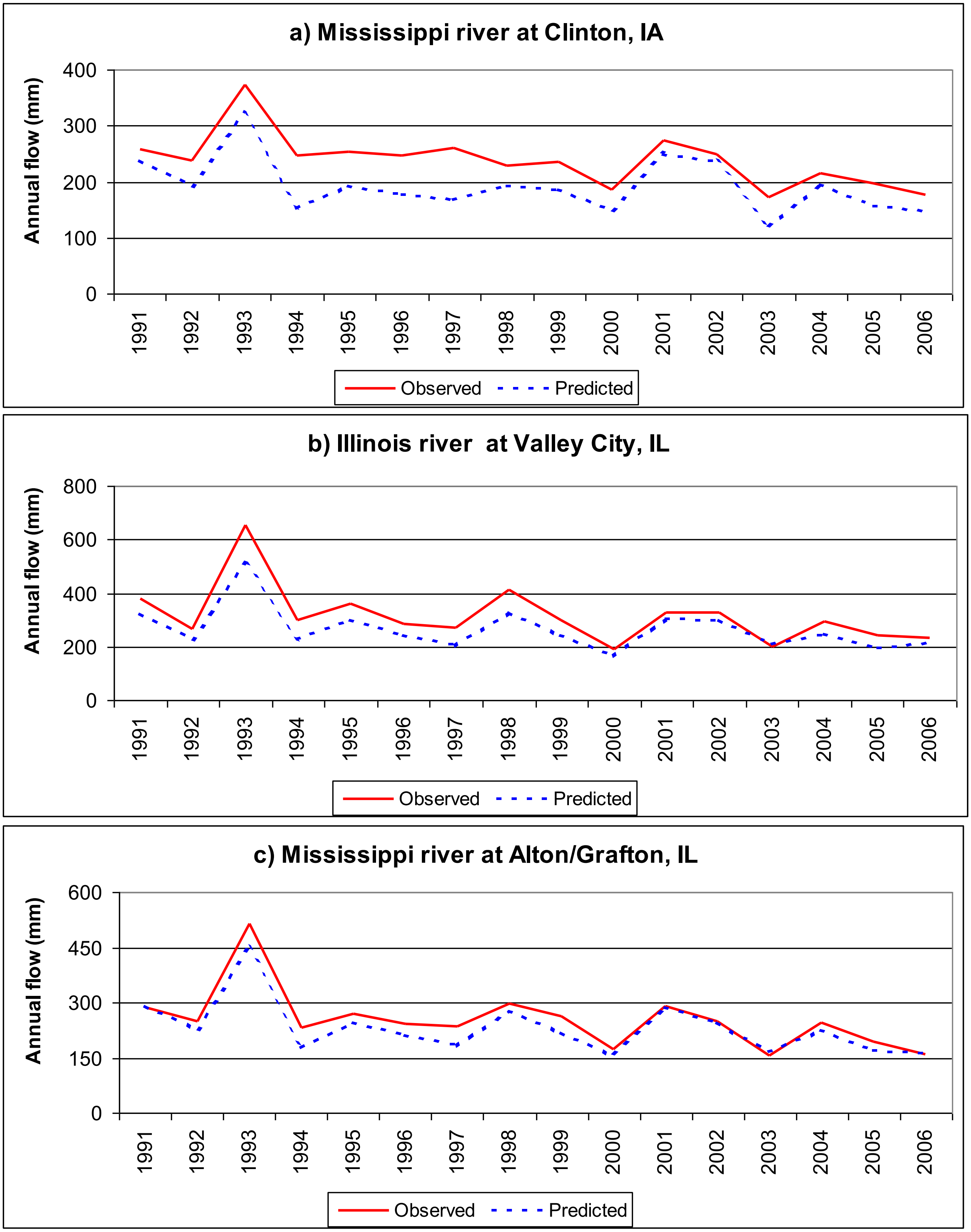


Figure 1-8 Average monthly stream flow for the Upper Mississippi River basin-Validation period

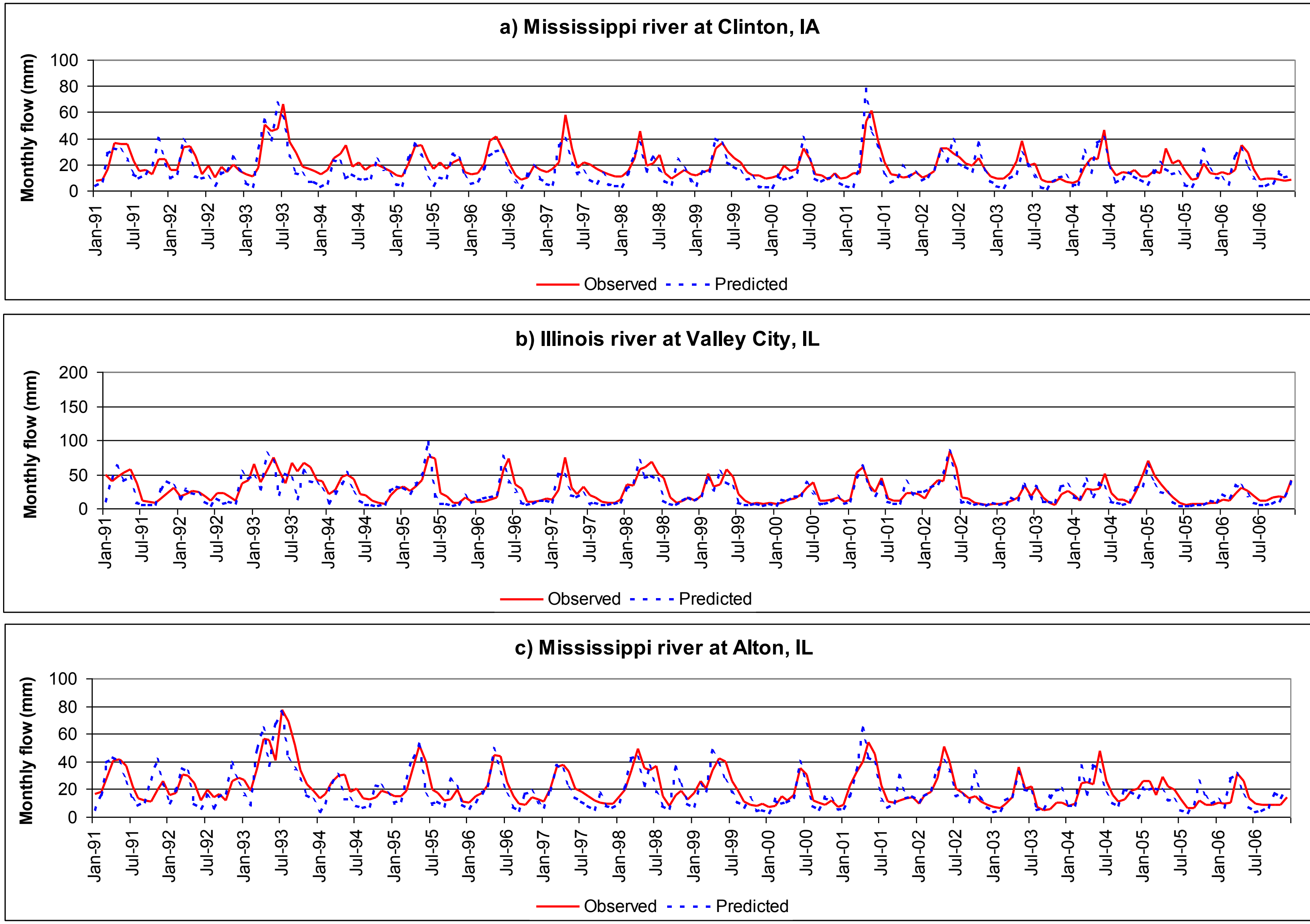


Table 1-5 Mean and standard deviation of the predicted and observed annual and monthly stream flow at selected gauging stations for the calibration period (1961-1990)

	Jordan, MN	Clinton, IA	Wapello, IA	Valley City, IL	Alton/Grafton, IL	Thebes, IL
Gauge details						
River	Minnesota river	Mississippi River	Iowa river	Illinois river	Mississippi River	Mississippi River
River reach-HUC	07020012	07080101	07080209	07130011	07110009	07140105
Drainage area (Km^2)	41,957.8	221,703.0	32,374.9	69,264.1	444,183.0	1,847,179
Data availability (period)	1961-1986, 1989-1990	1961-1990	1961-1990	1961-1990	1961-1990	1961-1990
Mean flow (mm)						
Annual-Predictions	108.8	175.7	253.3	270.8	221.0	111.8
Annual-Observations	98.9	196.8	233.3	302.8	227.6	103.1
Monthly-Predictions	8.8	14.7	21.1	22.6	18.4	9.3
Monthly-Observations	7.9	16.2	19.5	25.3	18.7	7.2
Standard deviation (mm)						
Annual-Predictions	52.9	61.3	104.2	77.1	71.5	34.0
Annual-Observations	59.1	55.0	108.7	97.9	75.5	32.0
Monthly-Predictions	11.8	12.5	21.9	20.8	14.3	6.0
Monthly-Observations	10.5	9.9	16.6	18.7	11.9	4.4

Table 1-6 Coefficient of determination and efficiency of the predicted and observed annual and monthly stream flow at selected gauging stations for the calibration period (1961-1990)

	Jordan, MN	**Clinton, IA**	**Wapello, IA**	**Valley City, IL**	**Alton/Grafton, IL**	**Thebes, IL**
Gauge Details						
River	Minnesota river	Mississippi River	Iowa river	Illinois river	Mississippi River	Mississippi River
River reach-HUC	07020012	07080101	07080209	07130011	07110009	07140105
Drainage area (Km^2)	41,957.8	221,704.0	32,374.9	69,264.1	444,183.0	1,847,179
Data availability (period)	1961-1986, 1989-1990	1961-1990	1961-1990	1961-1990	1961-1990	1961-1990
R^2						
Annual	0.83	0.85	0.92	0.91	0.89	0.92
Monthly	0.71	0.65	0.65	0.69	0.66	0.51
Nash and Sutcliffe Efficiency						
Annual	0.81	0.66	0.89	0.77	0.88	0.83
Monthly	0.63	0.42	0.38	0.59	0.52	-0.13

Table 1-7 Mean and standard deviation of the predicted and observed annual and monthly stream flow at selected gauging stations for the validation period (1991-2006)

	Jordan, MN	Clinton, IA	Wapello, IA	Valley City, IL	Alton/Grafton, IL	Thebes, IL
Gauge Details						
River	Minnesota river	Mississippi River	Iowa river	Illinois river	Mississippi River	Mississippi River
River reach-HUC	07020012	07080101	07080209	07130011	07110009	07140105
Drainage area (Km^2)	41,957.8	221,704.0	32,374.9	69,264.1	444,183.0	1,847,179
Data availability (period)	1991-2006	1991-2006	1991-2006	1991-2006	1991-2006	1961-1990
Mean flow (mm)						
Annual-Predictions	122.3	191.2	269.6	263.9	229.6	114.5
Annual-Observations	161.2	237.6	287.9	314.0	253.3	111.6
Monthly-Predictions	10.2	15.9	22.5	22.0	19.1	9.6
Monthly-Observations	13.1	19.5	24.0	26.2	20.8	5.1
Standard deviation (mm)						
Annual-Predictions	51.4	38.9	115.5	117.8	53.0	37.6
Annual-Observations	70.2	47.6	163.9	109.6	82.6	37.3
Monthly-Predictions	13.1	12.6	25.3	18.3	13.7	5.9
Monthly-Observations	15.3	11.0	24.1	18.6	12.9	3.2

Table 1-8 Coefficient of determination and efficiency of the predicted and observed annual and monthly stream flow at selected gauging stations for the validation period (1991-2006)

	Jordan, MN	Clinton, IA	Wapello, IA	Valley City, IL	Alton/Grafton, IL	Thebes, IL
Gauge Details						
River	Minnesota river	Mississippi River	Iowa river	Illinois river	Mississippi River	Mississippi River
River reach-HUC	07020012	07080101	07080209	07130011	07110009	07140105
Drainage area (Km^2)	41,957.8	221,704.0	32,374.9	69,264.1	444,183.0	1,847,179
Data availability (period)	1991-2006	1991-2006	1991-2006	1991-2006	1991-2006	1961-1990
R^2						
Annual	0.87	0.77	0.95	0.96	0.93	0.96
Monthly	0.73	0.68	0.73	0.67	0.65	0.66
Nash and Sutcliffe Efficiency						
Annual	0.57	-0.27	0.91	0.68	0.84	0.96
Monthly	0.70	0.47	0.69	0.59	0.56	--

Figure 1-9 Average annual sediment loads for the Upper Mississippi River basin

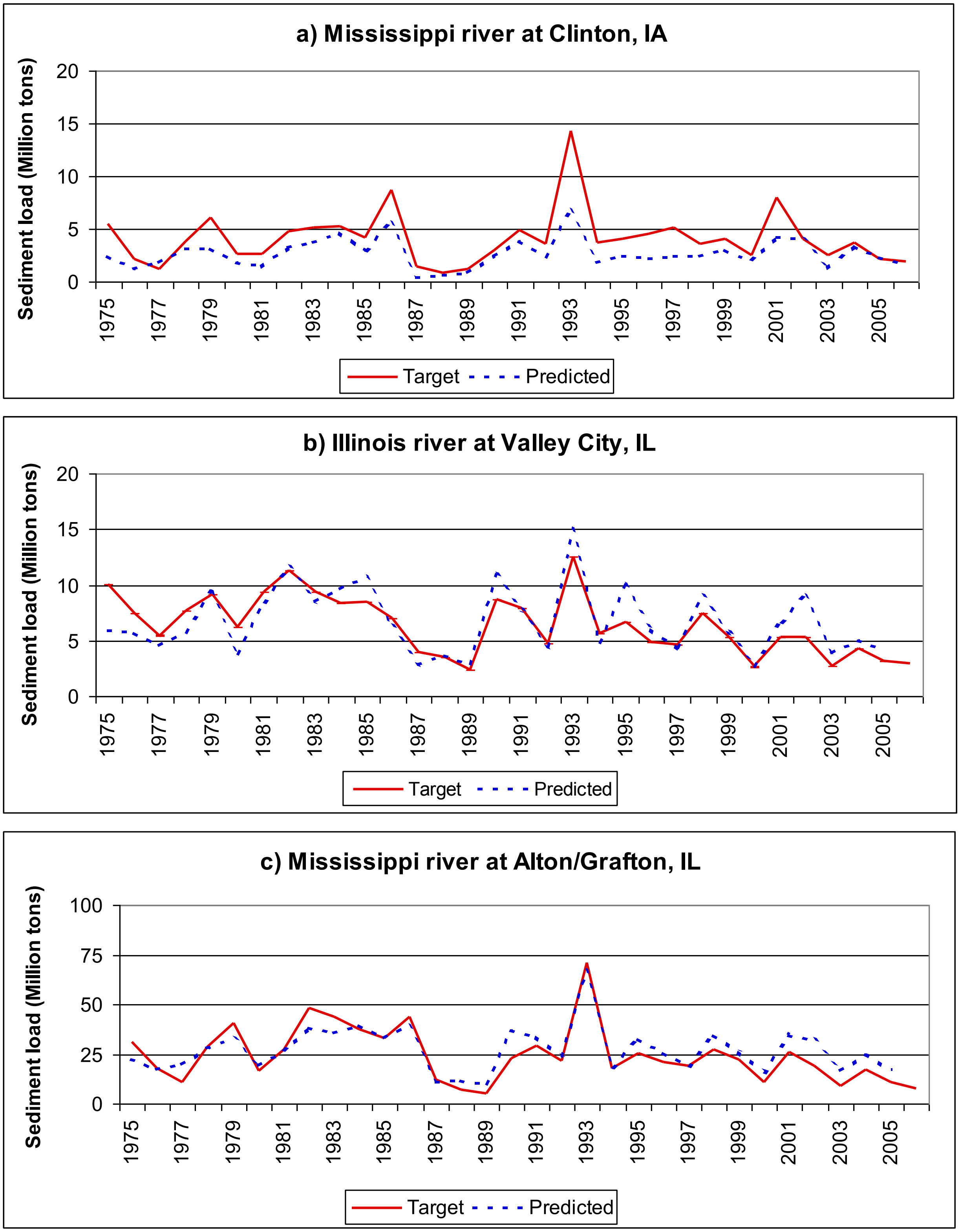


Figure 1-10 Average annual nitrite and nitrate Nitrogen (NO_2+NO_3) load for the Upper Mississippi River basin

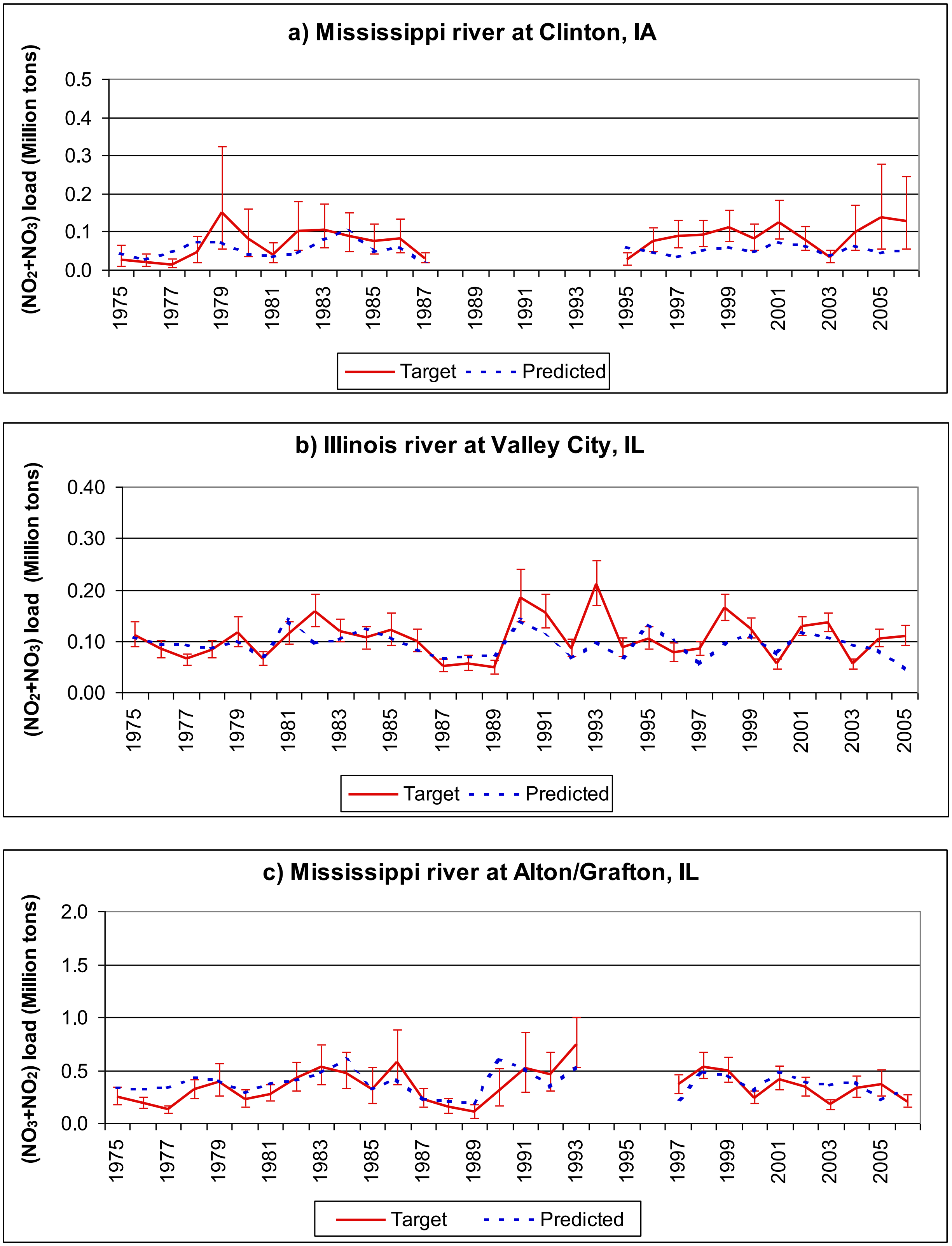


Figure 1-11 Average annual ammonia Nitrogen (NH_3) load for the Upper Mississippi River basin

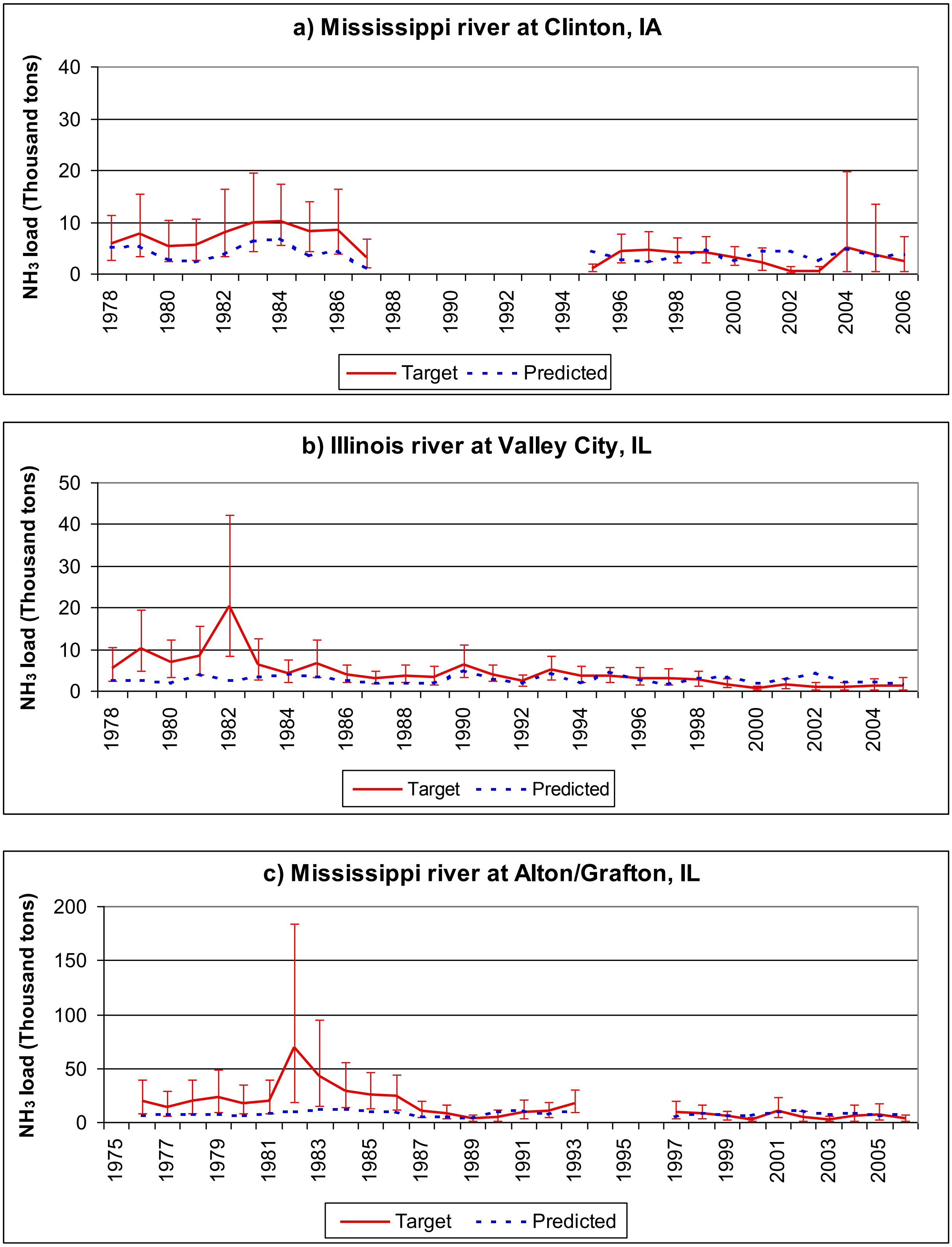


Figure 1-12 Average annual total Kjeldahl Nitrogen (TKN) load for the Upper Mississippi River basin

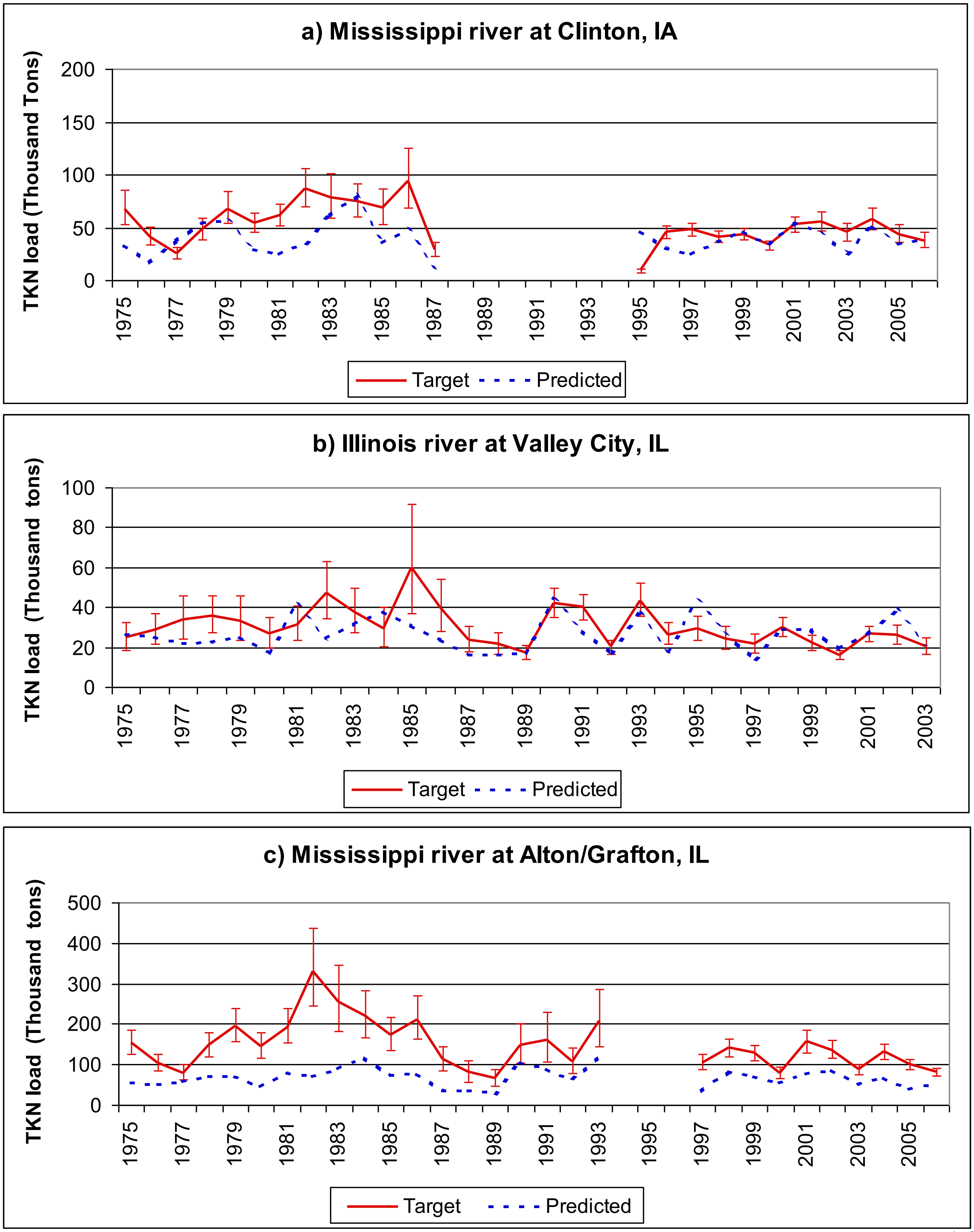


Figure 1-13 Average annual total Phosphorus (TP) load for the Upper Mississippi River basin

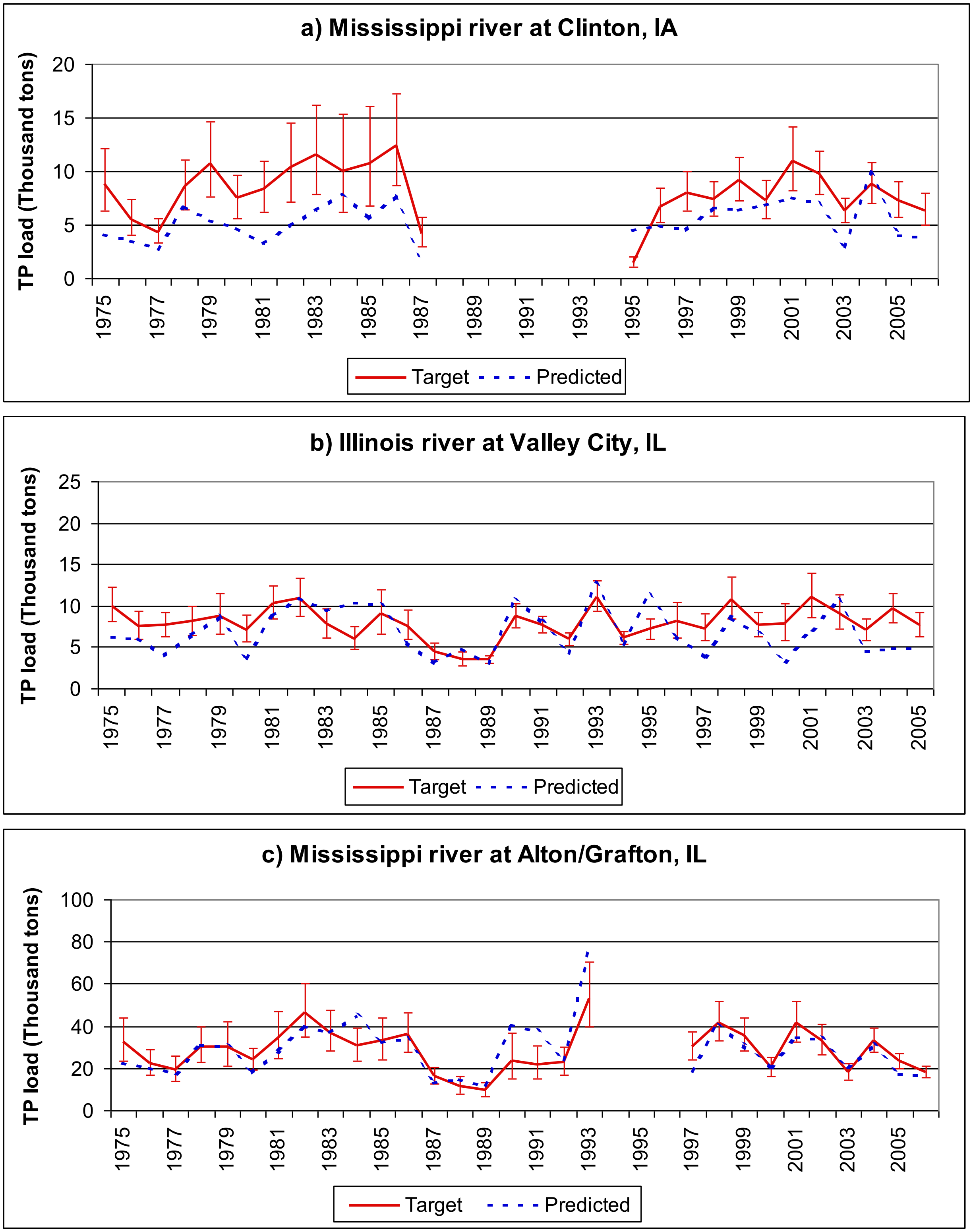
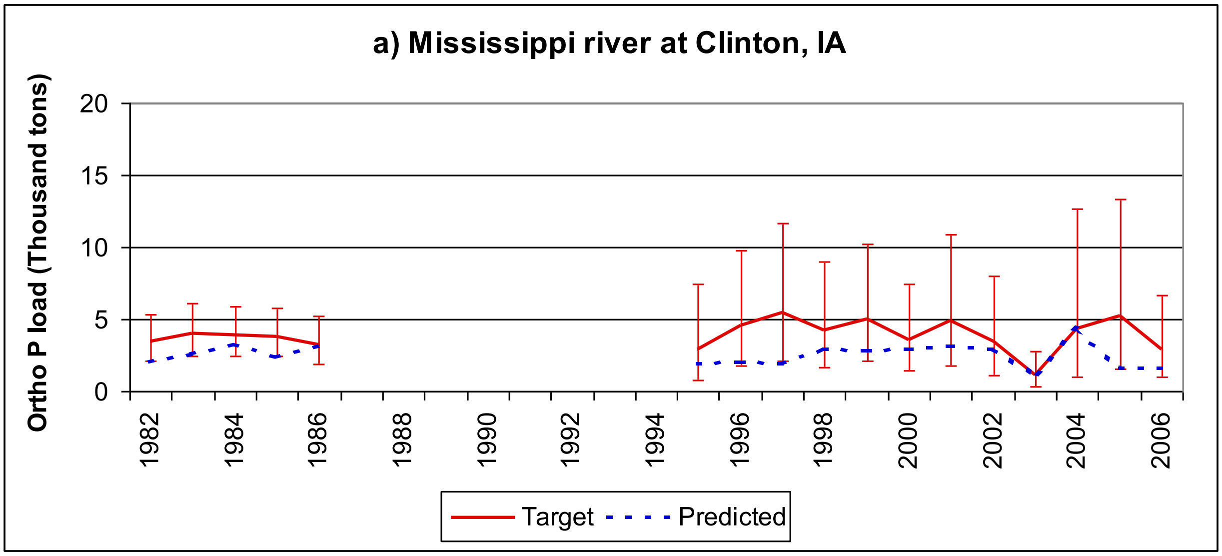
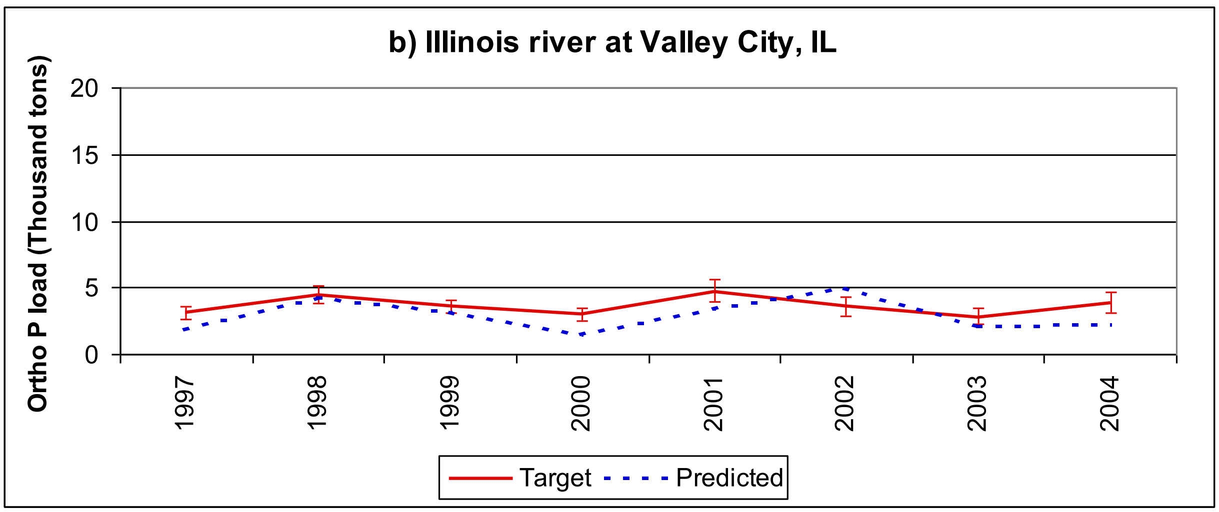


Figure 1-14 Average annual Ortho Phosphate (ortho P) load for the Upper Mississippi River basin





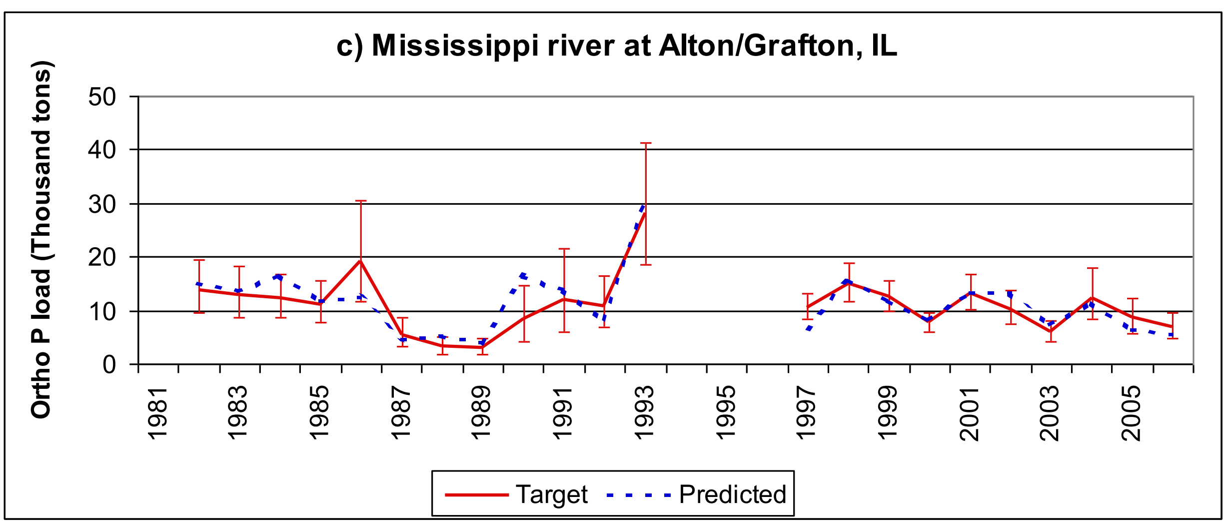


Figure 1-15 Average annual soluble Atrazine load for the Upper Mississippi River basin

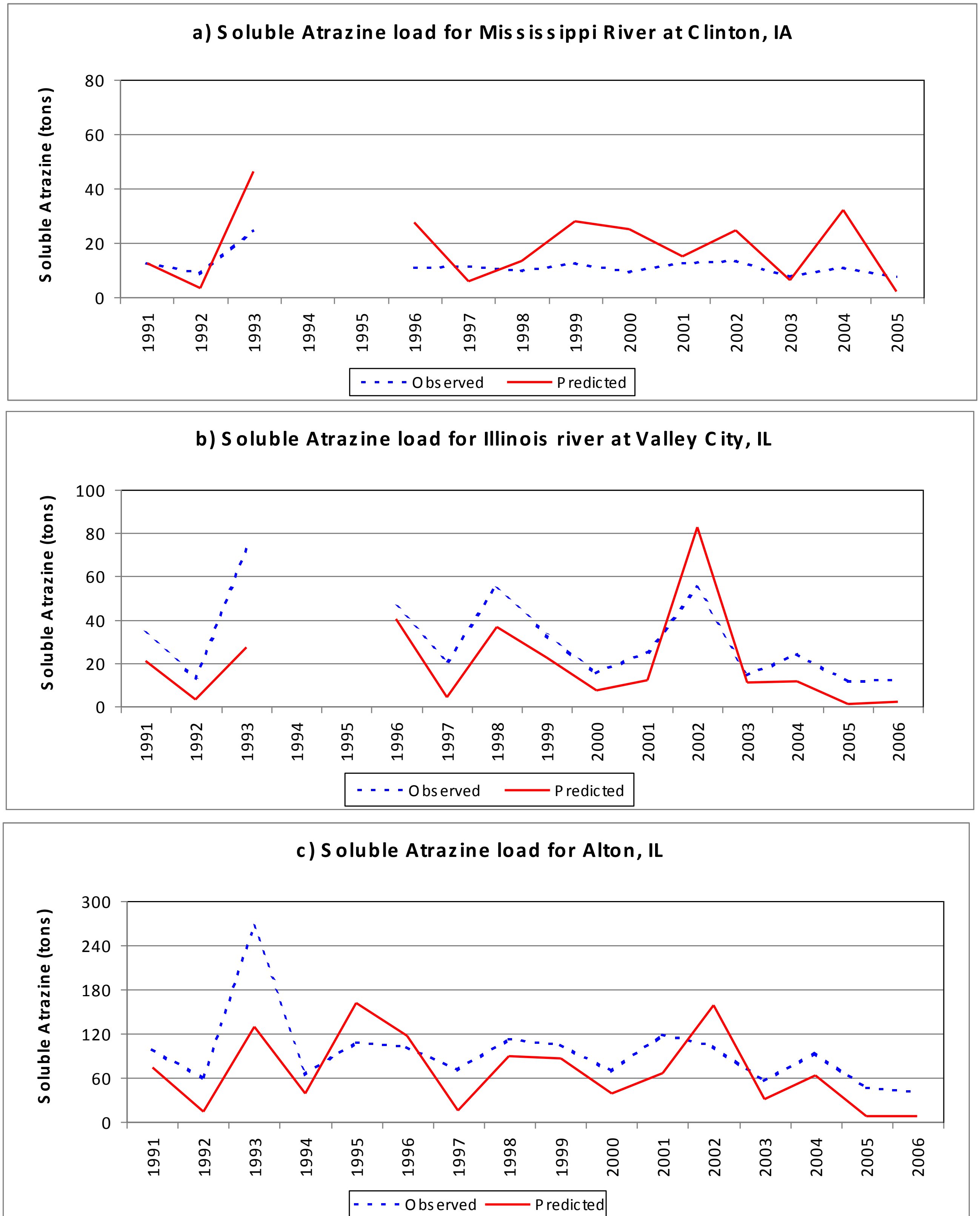


Table 1-9 Average annual Suspended Sediment load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Minnesota river at Jordan, MN	07020012	895,566	1,265,214
Mississippi River at Clinton, IA	07080101	2,635,672	4,088,298
Iowa river at Wapello, IA	07080209	2,416,772	3,632,896
Illinois river at Valley City, IL	07130011	6,626,000	6,398,700
Mississippi River at Grafton/Alton, IL	07110009	26,668,813	24,314,751
Mississippi River at Thebes, IL	07140105	80,365,000	98,626,591

Table 1-10a Average annual Nitrate and Nitrite Nitrogen load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Minnesota river at Jordan, MN	07020012	47,393	64,200
Mississippi River at Hastings, MN	07010206	64,585	43,969
Mississippi River at Clinton, IA	07080101	51,816	76,982
Iowa river at Wapello, IA	07080209	45,708	65,402
Illinois river at Valley City, IL	07130011	93,419	105,404
Mississippi River at Grafton/Alton, IL	07110009	373,755	346,769
Mississippi River at Thebes, IL	07140105	478,487	505,336

Table 1-10b Average annual Total Kjheldahl Nitrogen load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Minnesota river at Jordan, MN	07020012	1,717	7,223
Mississippi River at Hastings, MN	07010206	7,353	18,688
Mississippi River at Clinton, IA	07080101	39,246	52,453
Iowa river at Wapello, IA	07080209	5,507	15,214
Illinois river at Valley City, IL	07130011	26,336	30,213
Mississippi River at Grafton/Alton, IL	07110009	65,972	145,988
Mississippi River at Thebes, IL	07140105	263,399	286,230

Table 1-10c Average annual Ammonia Nitrogen load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Minnesota river at Jordan, MN	07020012	234	747
Mississippi River at Hastings, MN	07010206	749	1,728
Mississippi River at Clinton, IA	07080101	3,744	4,896
Iowa river at Wapello, IA	07080209	633	1,360
Illinois river at Valley City, IL	07130011	2,705	4,419
Mississippi River at Grafton/Alton, IL	07110009	7,498	15,158
Mississippi River at Thebes, IL	07140105	24,867	25,089

Table 1-11a Average annual Total Phosphorus load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Minnesota river at Jordan, MN	07020012	1,030	1,321
Mississippi River at Hastings, MN	07010206	2,747	3,188
Mississippi River at Clinton, IA	07080101	5,273	8,077
Iowa river at Wapello, IA	07080209	2,568	2,979
Illinois river at Valley City, IL	07130011	6,862	7,889
Mississippi River at Grafton/Alton, IL	07110009	28,574	28,604
Mississippi River at Thebes, IL	07140105	59,941	68,279

Table 1-11b Average annual Ortho Phosphate load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Minnesota river at Jordan, MN	07020012	545	639
Mississippi River at Hastings, MN	07010206	1,727	1,368
Mississippi River at Clinton, IA	07080101	2,481	3,874
Iowa river at Wapello, IA	07080209	1,315	1,510
Illinois river at Valley City, IL	07130011	2,866	3,625
Mississippi River at Grafton/Alton, IL	07110009	11,356	11,055
Mississippi River at Thebes, IL	07140105	19,394	12,098

Table 1-12 Average annual Atrazine load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Mississippi River at Clinton, IA	07080101	18.6	11.6
Iowa river at Wapello, IA	07080209	7.4	11.6
Illinois river at Valley City, IL	07130011	20.2	30.8
Mississippi River at Grafton/Alton, IL	07110009	68.7	94.3

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Chapter 2

Calibration and Validation of CEAP-HUMUS for the Chesapeake Bay Watershed

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Chapter 2 describes results of calibration and validation of CEAP-HUMUS model setup for the Chesapeake Bay Watershed. More details on procedures used in the calibration-validation process are presented in Chapter 1.

(Status: Complete)

This chapter addresses calibrations of APEX and HUMUS/SWAT for the Chesapeake Bay (CB) watershed and to validate the CEAP modeling framework at selected gauging stations. In this report, only the results for rivers that drain to Chesapeake Bay will be reported rather than the entire Mid Atlantic River basin.

Calibration results of the average annual runoff at 8-digit watersheds

Average annual water yield from cultivated and non-cultivated land

The average annual simulated and targeted runoff of the 8-digit watersheds in the Chesapeake Bay watershed is shown in Figure 2-2. Targeted and simulated runoff patterns concur with the precipitation patterns of this watershed. The regression relationship between targeted and simulated runoff at 8-digit watersheds (R^2 is 0.32), the means and standard deviations of annual runoff (of all the 8-digit watersheds in the basin) indicate that the model prediction is satisfactory (Figure 2-3 and Table 2-1). All the 8-digit watersheds except 9 were within the stipulated calibration goal of less than 20 % difference between predictions and target values of average annual water yield (Figure 2-3).

Annual and monthly flow calibration and validation at stream gages

Five USGS stream gages were selected in the CB watershed for annual and monthly flow calibration and validation (Figure 2-1). Calibration was performed for the period 1961 to 1990 to ensure that there was a reasonable agreement between predicted and observed flow at annual and monthly time steps. The model was validated for annual and monthly flows in the same stream gages for the period 1991 to 2006 without changing the calibrated input parameters.

Flow calibration and validation results at annual and monthly time step are shown in Figures 2-4 through 2-7 and Tables 2-2 through 2-5 for the stream gages located in Susquehanna river (Danville-PA, Harrisburg-PA, and Conowingo-MD), Potomac river (Little Falls-DC), and James river (Cartersville-VA).

Observed and simulated flows at annual and monthly time steps matched very well for the calibration period (Figures 2-4 and 2-5). Means and standard deviations of predictions and observations are in close agreement (Table 2-2). In addition, the coefficient of determination is greater than 0.6 (R^2) and NSE is greater than 0.5 (Table 2-3) for all the gauges (except Susquehanna river at Conowingo, MD) during the calibration period. At Conowingo, MD the under-estimation of flow affected the model performance. However, in the same river, all the other upstream reaches show acceptable model performance (Tables 2-2 and 2-3, Figures 2-4 and 2-5). In summary, during calibration period, the model performance evaluation measures suggest an overall good agreement between observed and simulated flows at the annual and monthly time step, throughout the watershed.

Annual and monthly flow results for the above listed gauging stations for validation period are shown in (Figure 2-6, and 2-7 and Tables 2-4 and 2-5). Based on R2 and NSE it can be seen that all the gauges show acceptable predicted results from model. In summary, HUMUS-SWAT is able to capture the annual and monthly flow patterns very well in the Chesapeake Bay watershed.

Sediment calibration

Predicted sediment results were validated in 5 different gauging stations (Figure 2-1) in CB watershed as outlined in Table 2-6. To limit the contents of this section, detailed results are shown only for three locations. However, the means are shown for all stations (Table 2-6). Figure 2-8 shows a detailed comparison of predicted and target sediment loads in Susquehanna river at Conowingo, MD, Potomac river at Chainbridge, DC and James river at Cartersville, VA. In general, there is over-estimation (Table 2-6, Figure 2-8) of annual sediment load in different locations (except for Potomac river at Chainbridge, DC). For all the rivers analyzed, there is close match between predictions and target values of sediment load (Figure 2-8). In all the gauges the predicted loads are within the confidence limits (where available) of the target values. Although within the confidence limits, the predicted sediment load in James river at Cartersville shows slightly high over estimation (about 35 %). The possible reasons are: 1) There is sediment aggregation (sediment in – sediment out is –ve) in all the reaches of James river except one or two; and 2) modeled sediment trapping in the reservoirs is not adequate. Considering the quality of predicted sediment loads in all the places of validation, we could say the model results are adequate for making scenario trials.

Nutrient Calibration

Predicted nutrient results were validated in five gauging stations (Figure 2-1) in CB watershed as outlined in Tables 2-7 and Table 2-8. To limit the contents of this section, detailed results are shown for three locations only. The predicted and target means are shown for all the five stations (Table 2-7 and Table 2-8). Figures 2-9 through 2-12 depict a detailed comparison of predicted and target nutrient loads (various constituents of N and P) in the Susquehanna River at Conowingo, MD, Potomac River at Chainbridge, DC and James River at Cartersville, VA. Error bars or the upper and lower confidence levels of target values are also presented. In general, the predicted nutrient loads from HUMUS-SWAT are in good agreement with the target values and within the uncertainty limits of target values for all the nutrient constituent-location combinations, except orthophosphate for the Potomac River, suggesting the suitability of the model for making scenario trials.

Atrazine calibration

For this watershed, the availability of atrazine observations was limited to one gauge only. Therefore, predicted atrazine results were validated in that gauge as outlined in Table 2-9 and Figure 2-13. Figure 2-13 shows a detailed comparison of predicted and target atrazine loads in Susquehanna river at Conowingo, MD. In general, the pattern/trend and magnitude of predicted atrazine loads from HUMUS-SWAT are in agreement with the target values; however, the predicted atrazine loads are under-estimated. The under-estimation can be attributed to under-estimation of flow, uncertainties in observations, and the procedure used to obtain annual loads from daily grab samples.

Table 2-1 Basin-average statistics for predicted and target annual water yield for all 8-digit watersheds in the CB watershed — Combined water yield results from APEX and SWAT after calibration (1961–90)

Calibration	Statistic	Value
Predictions	Mean (mm)	410.1
(After calibration)	Standard deviation (mm)	50.9
Observations	Mean (mm)	428.5
	Standard deviation (mm)	76.0

Figure 2-1 Location of the Chesapeake Bay watershed and sampling locations

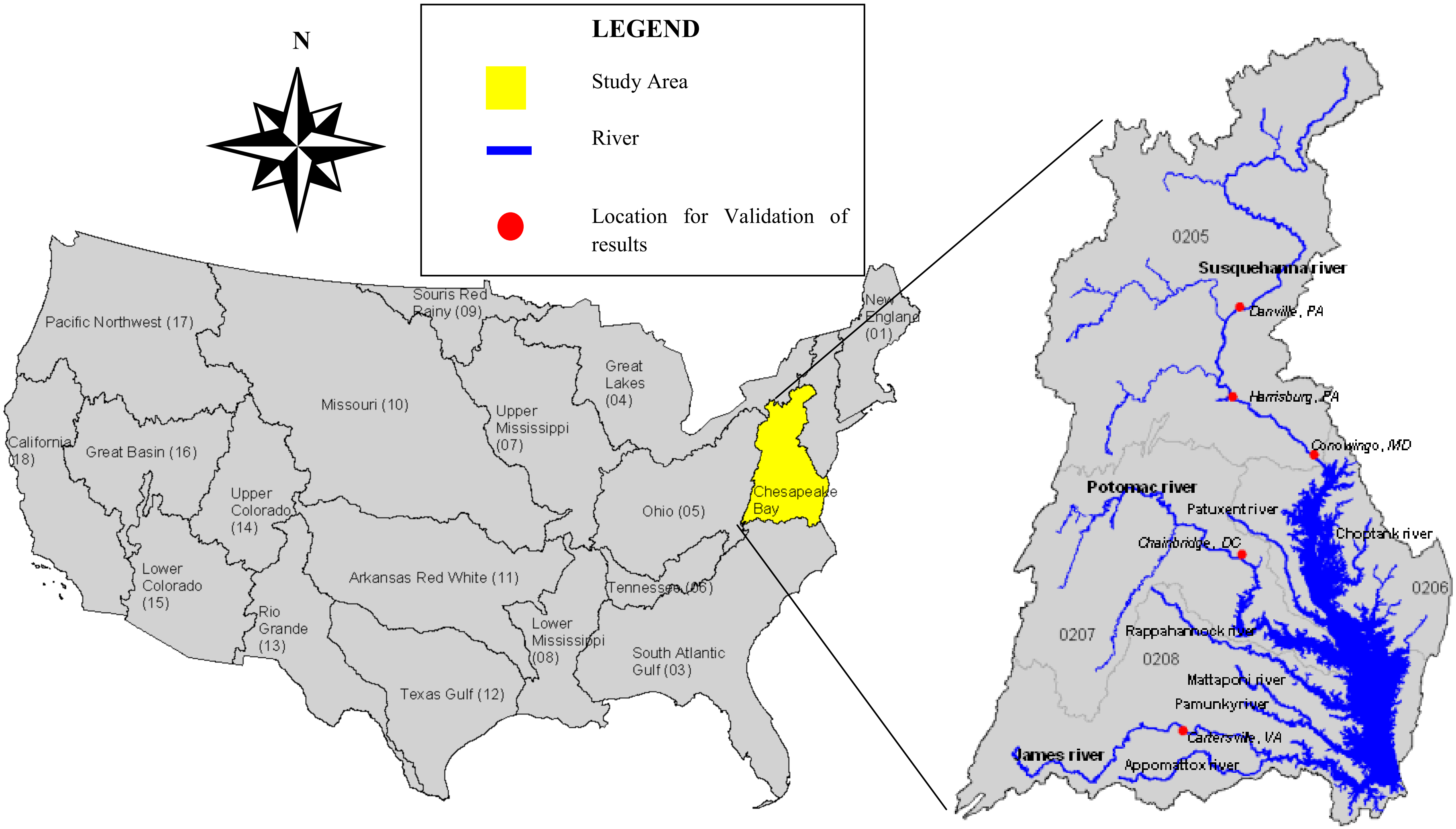

Figure 2-2 Average annual water yield of all 8-digit watersheds in the Chesapeake Bay watershed from cultivated and non-cultivated area (combined water yield from APEX and SWAT)

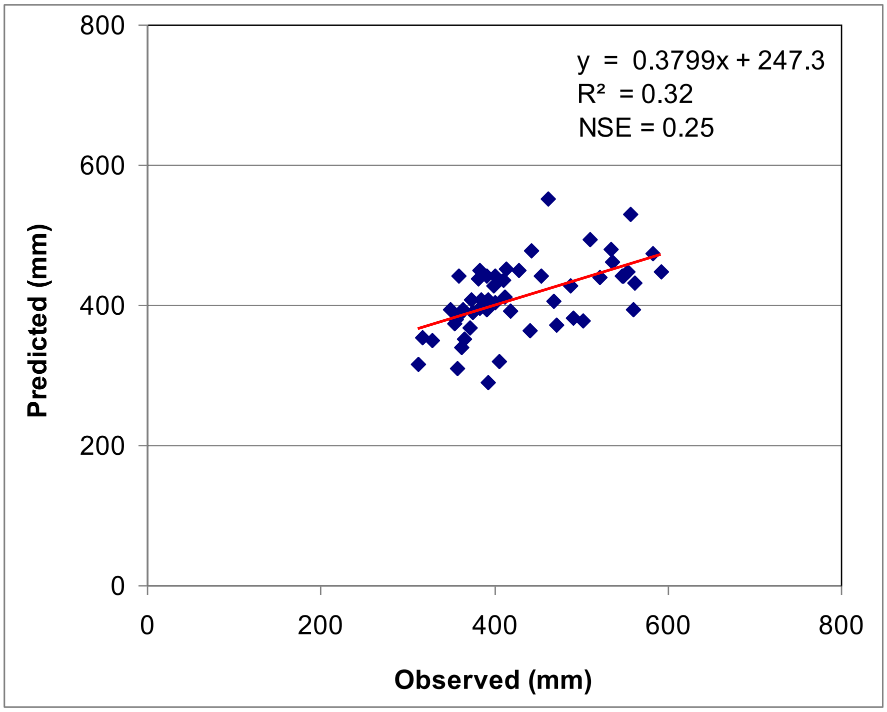

Figure 2-3 Percentage difference between predictions and observations of annual average flow in the CB watershed (combined water yield from APEX and SWAT after calibration

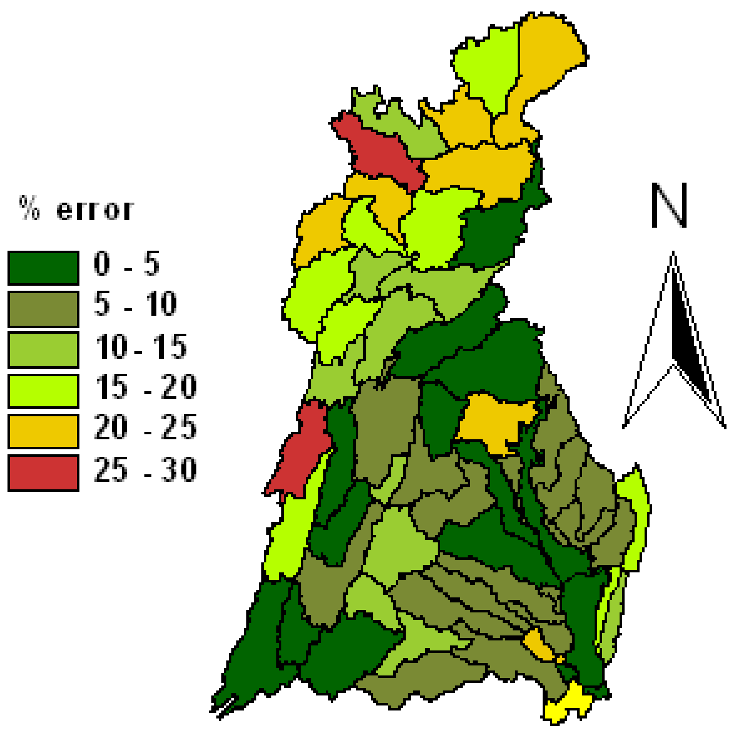

Figure 2-4 Average annual stream flow for the Chesapeake Bay river basin-Calibration period

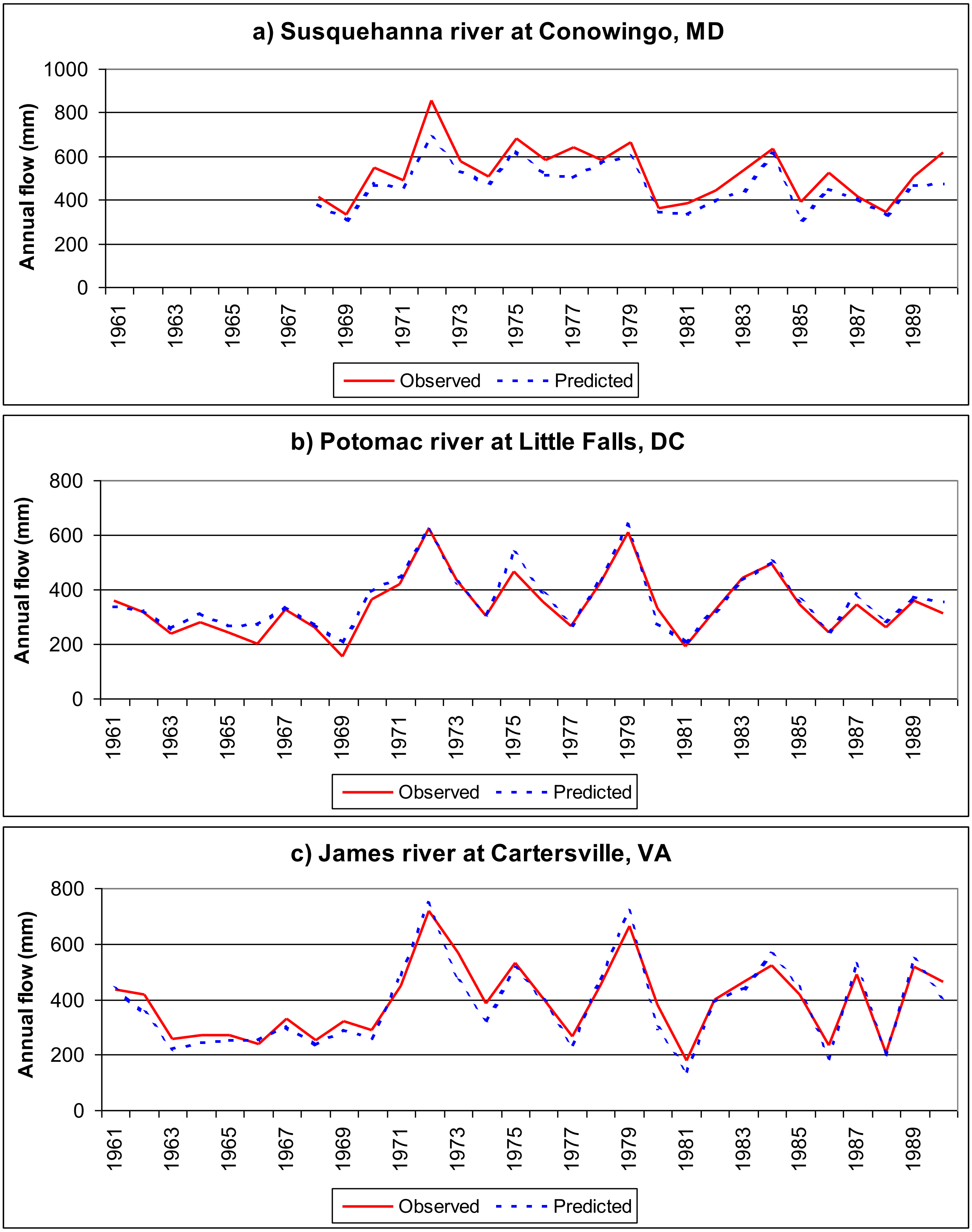

Figure 2-5 Average monthly stream flow for the Chesapeake Bay river basin-Calibration period

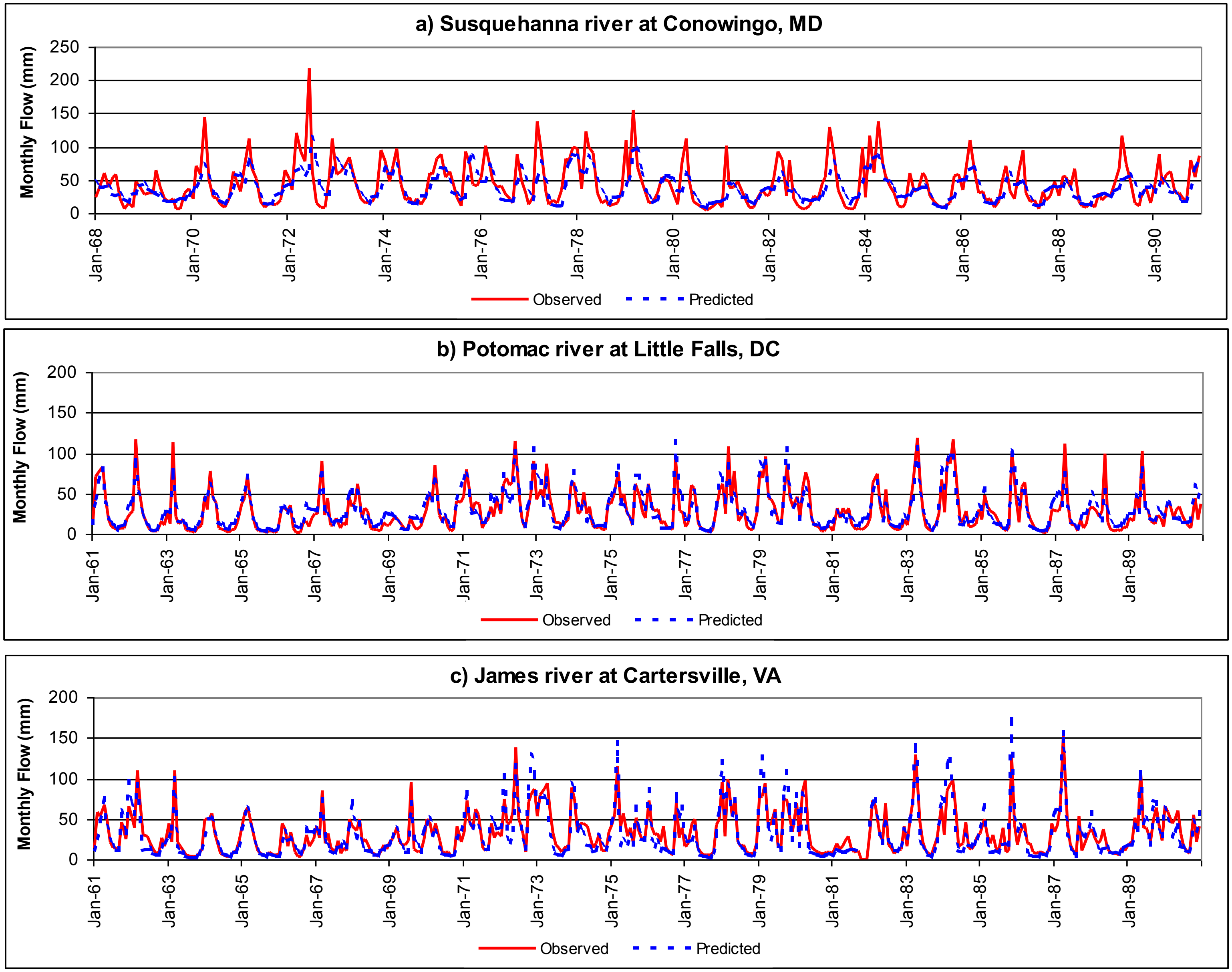

Figure 2-6 Average annual stream flow for the Chesapeake Bay river basin-Validation period

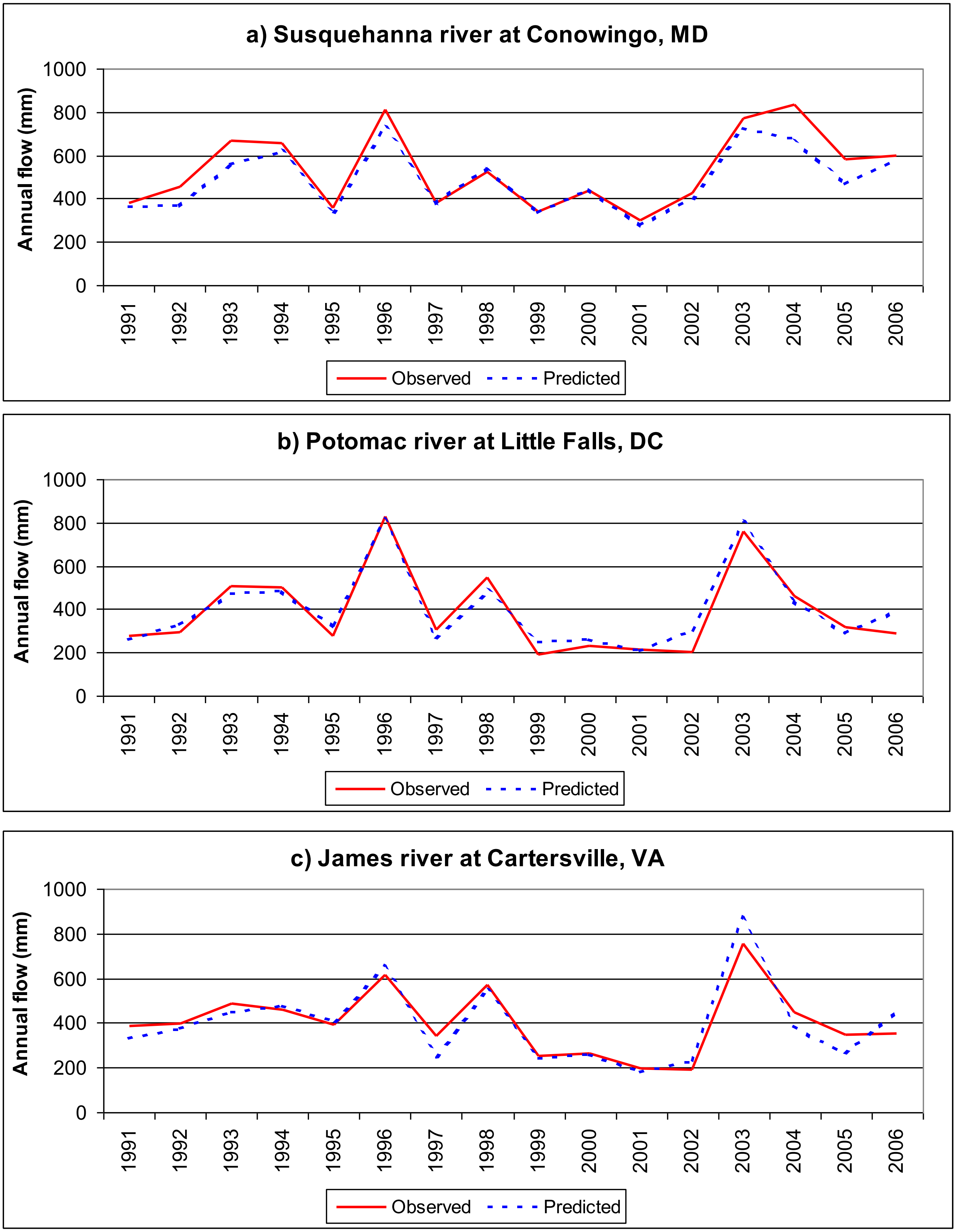

Figure 2-7 Average monthly stream flow for the Chesapeake Bay basin-Validation period

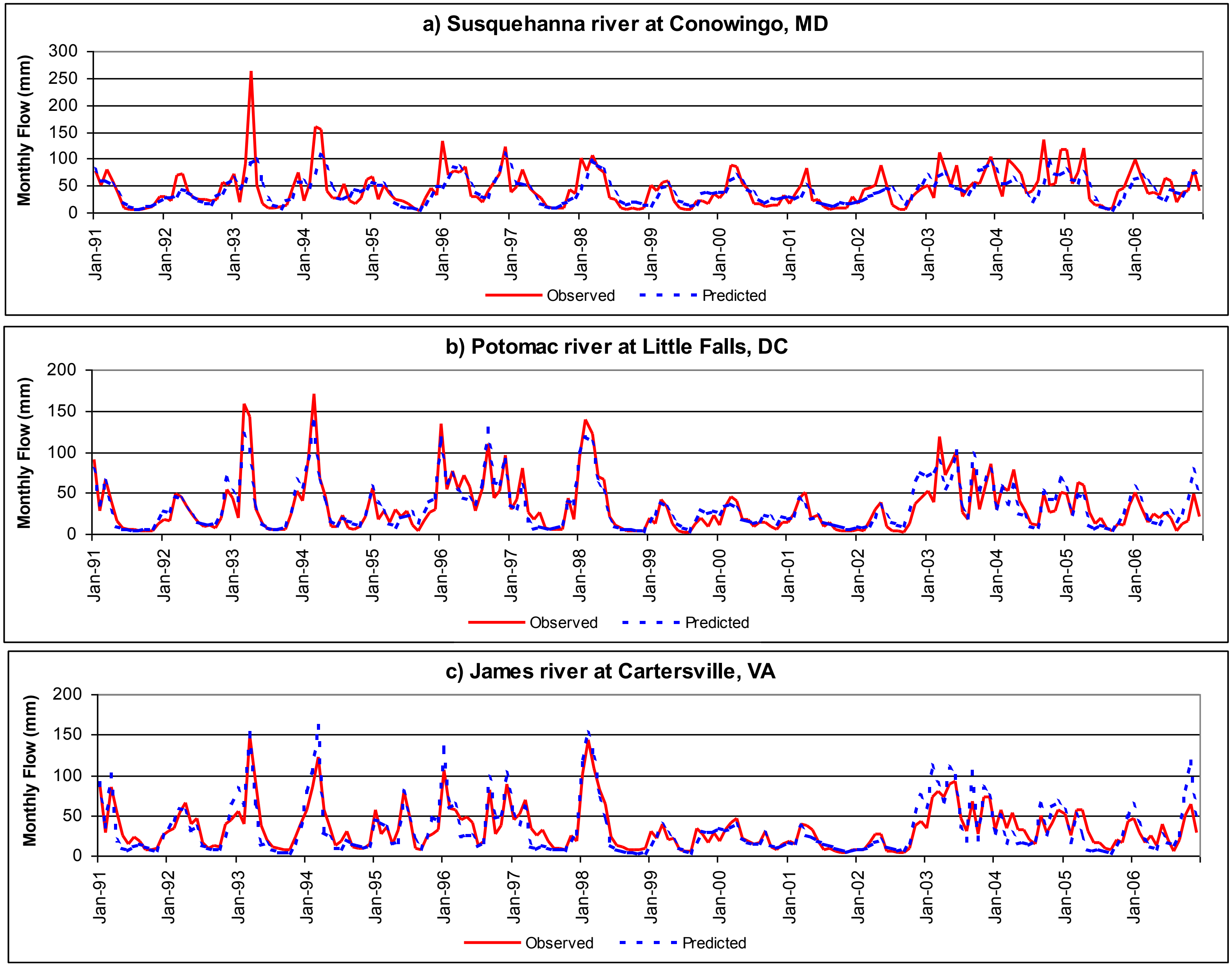

Table 2-2 Mean and standard deviation of the predicted and observed annual and monthly stream flow at selected gauging stations for the calibration period (1961-1990)

	Danville, PA	**Harrisburg, PA**	**Conowingo, MD**	**Little Falls, DC**	**Cartersville, VA**
Gauge details					
River	Susquehanna river	Susquehanna river	Susquehanna river	Potomac river	James river
River reach-HUC	02050107	02050305	02050306	02070008	02080205
Drainage area (Km^2)	29,059.7	62,418.7	70,188.7	29,940.3	16,192.6
Data availability (period)	1961-1990	1961-1990	1968-1990	1961-1990	1961-1990
Mean flow (mm)					
Annual-Predictions	405.6	427.8	462.2	357.3	376.2
Annual-Observations	466.6	481.2	522.2	341.8	391.5
Monthly-Predictions	34.4	36.3	38.5	30.1	31.9
Monthly-Observations	38.9	40.1	43.6	28.5	32.5
Standard deviation (mm)					
Annual-Predictions	109.7	108.1	105.3	107.5	152.6
Annual-Observations	124.1	127.2	128.7	111.0	134.2
Monthly-Predictions	26.5	20.7	20.3	23.2	30.2
Monthly-Observations	33.5	33.2	33.0	25.6	26.8

Table 2-3 Coefficient of determination and efficiency of the predicted and observed annual and monthly stream flow at selected gauging stations for the calibration period (1961-1990)

	Danville, PA	**Harrisburg, PA**	**Conowingo, MD**	**Little Falls, DC**	**Cartersville, VA**
Gauge details					
River	Susquehanna river	Susquehanna river	Susquehanna river	Potomac river	James river
River reach-HUC	02050107	02050305	02050306	02070008	02080205
Drainage area (Km^2)	29,059.7	62,418.7	70,188.7	29,940.3	16,192.6
Data availability (period)	1961-1990	1961-1990	1968-1990	1961-1990	1961-1990
R^2					
Annual	0.98	0.96	0.90	0.95	0.94
Monthly	0.79	0.62	0.46	0.83	0.83
Nash and Sutcliffe Efficiency					
Annual	0.72	0.76	0.66	0.93	0.90
Monthly	0.77	0.58	0.44	0.83	0.79

Table 2-4 Mean and standard deviation of the predicted and observed annual and monthly stream flow at selected gauging stations for the validation period (1991-2006)

	Danville, PA	**Harrisburg, PA**	**Conowingo, MD**	**Little Falls, DC**	**Cartersville, VA**
Gauge details					
River	Susquehanna river	Susquehanna river	Susquehanna river	Potomac river	James river
River reach-HUC	02050107	02050305	02050306	02070008	02080205
Drainage area (Km^2)	29,059.7	62,418.7	70,188.7	29,940.3	16,192.6
Data availability (period)	1991-2006	1991-2006	1991-2006	1991-2006	1991-2006
Mean flow (mm)					
Annual-Predictions	458.6	477.6	486.6	397.0	396.7
Annual-Observations	530.9	523.8	532.0	386.5	401.9
Monthly-Predictions	38.7	40.4	40.6	33.3	33.4
Monthly-Observations	44.3	43.7	44.4	32.2	33.5
Standard deviation (mm)					
Annual-Predictions	146.0	147.7	146.5	183.6	179.9
Annual-Observations	148.0	163.3	175.5	196.1	152.8
Monthly-Predictions	27.8	24.3	23.4	28.2	33.0
Monthly-Observations	36.6	35.3	35.6	31.8	27.2

Table 2-5 Coefficient of determination and efficiency of the predicted and observed annual and monthly stream flow at selected gauging stations for the validation period (1991-2006)

	Danville, PA	**Harrisburg, PA**	**Conowingo, MD**	**Little Falls, DC**	**Cartersville, VA**
Gauge details					
River	Susquehanna river	Susquehanna river	Susquehanna river	Potomac river	James river
River reach-HUC	02050107	02050305	02050306	02070008	02080205
Drainage area (Km^2)	29,059.7	62,418.7	70,188.7	29,940.3	16,192.6
Data availability (period)	1991-2006	1991-2006	1991-2006	1991-2006	1991-2006
R^2					
Annual	0.97	0.98	0.93	0.94	0.90
Monthly	0.73	0.67	0.52	0.87	0.84
Nash and Sutcliffe Efficiency					
Annual	0.72	0.89	0.84	0.93	0.85
Monthly	0.70	0.63	0.50	0.86	0.75

Figure 2-8 Average annual sediment load Chesapeake Bay basin

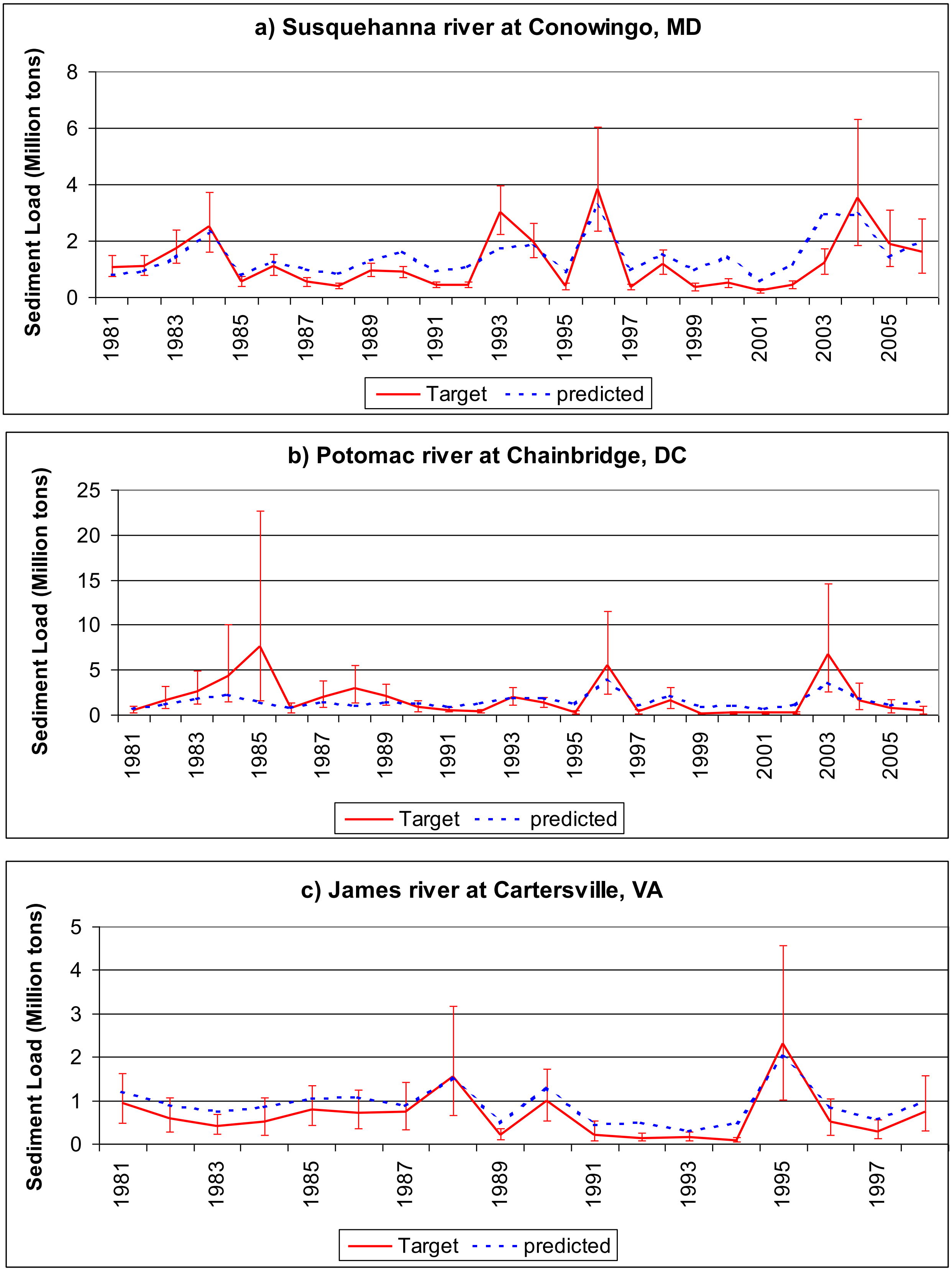

Figure 2-9 Average annual nitrite and nitrate Nitrogen (NO_2+NO_3) load for the Chesapeake Bay basin

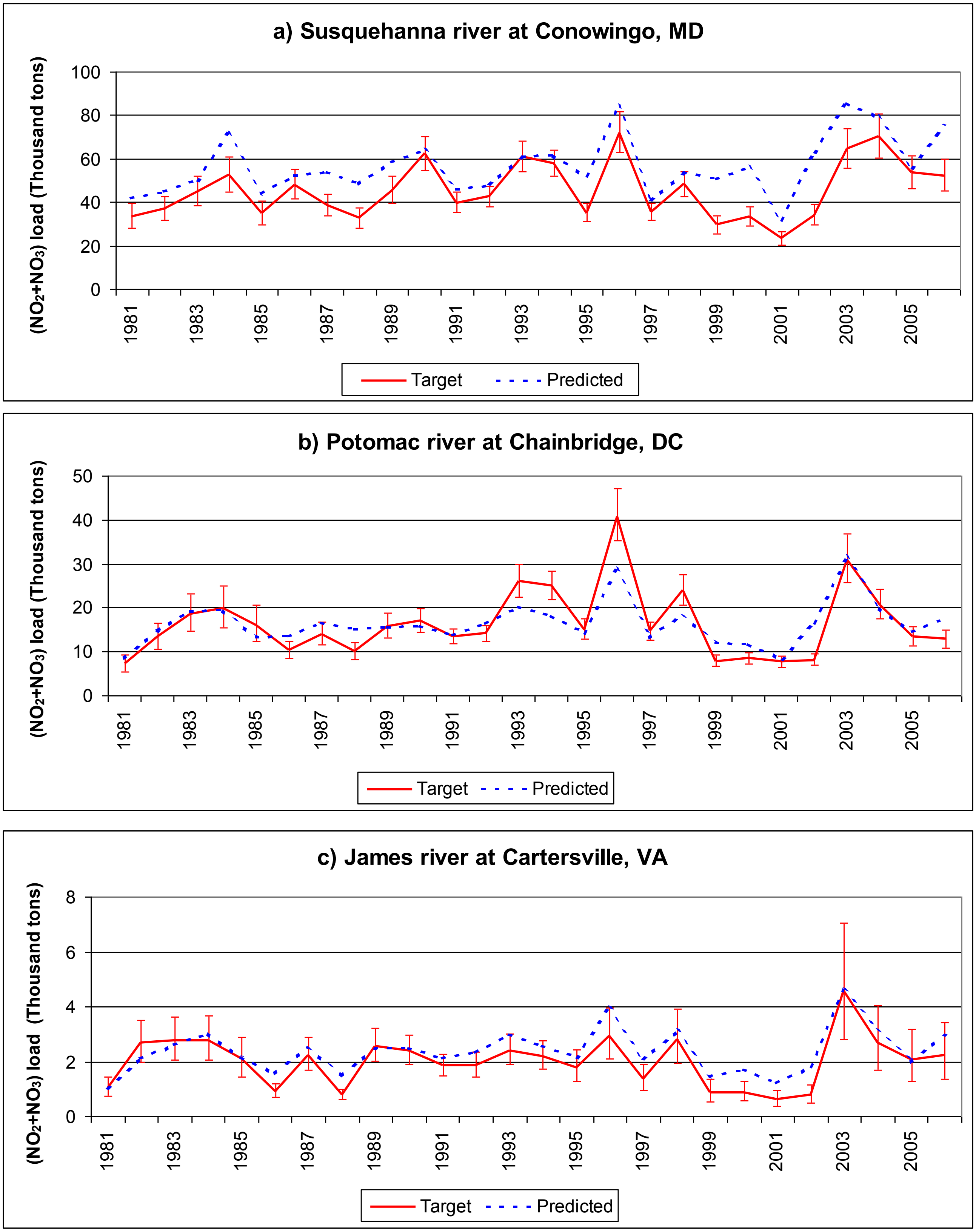

Figure 2-10 Average annual total Nitrogen (TN) load for the Chesapeake Bay basin

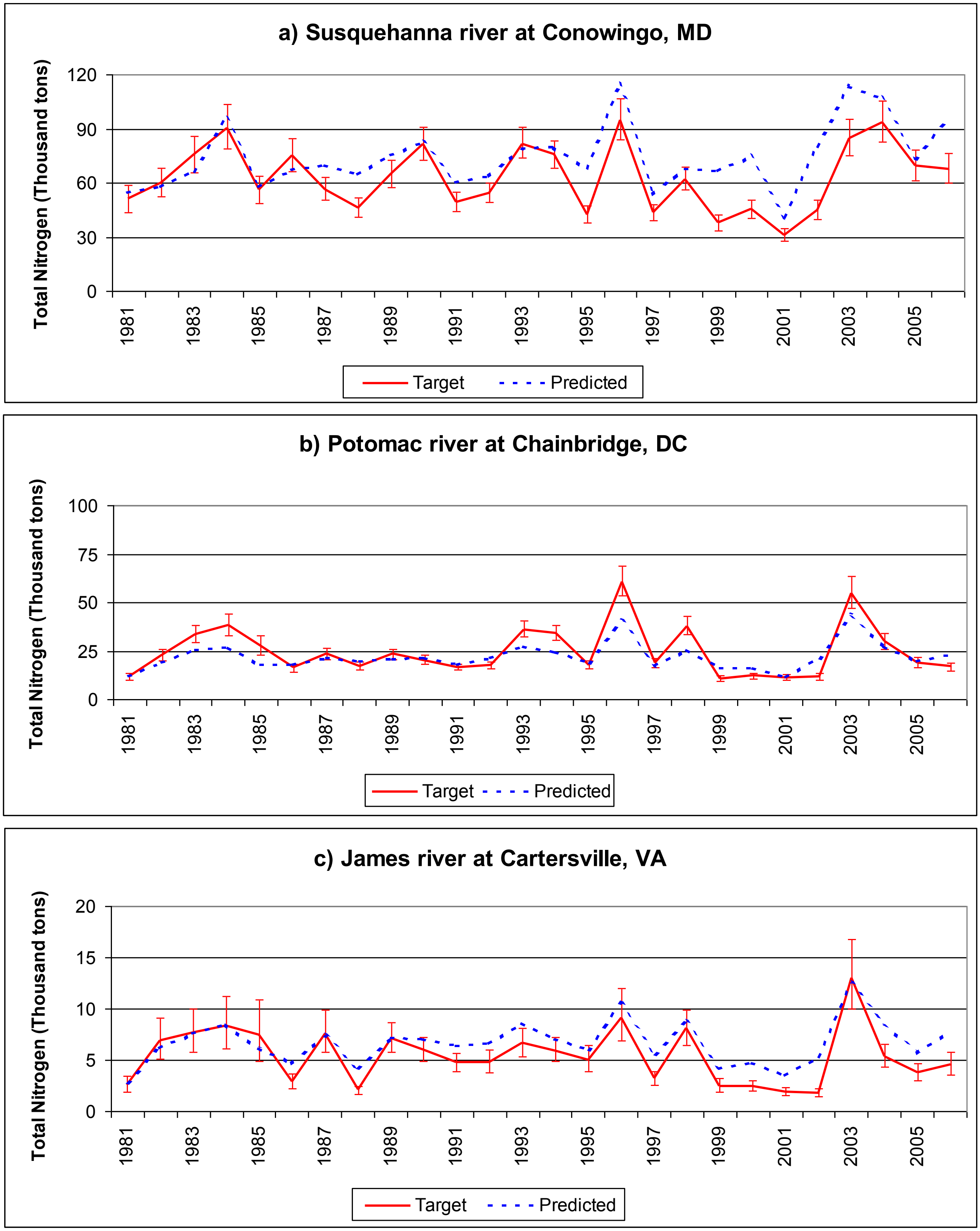

Figure 2-11 Average annual total Phosphorus (TP) load for the Chesapeake Bay basin

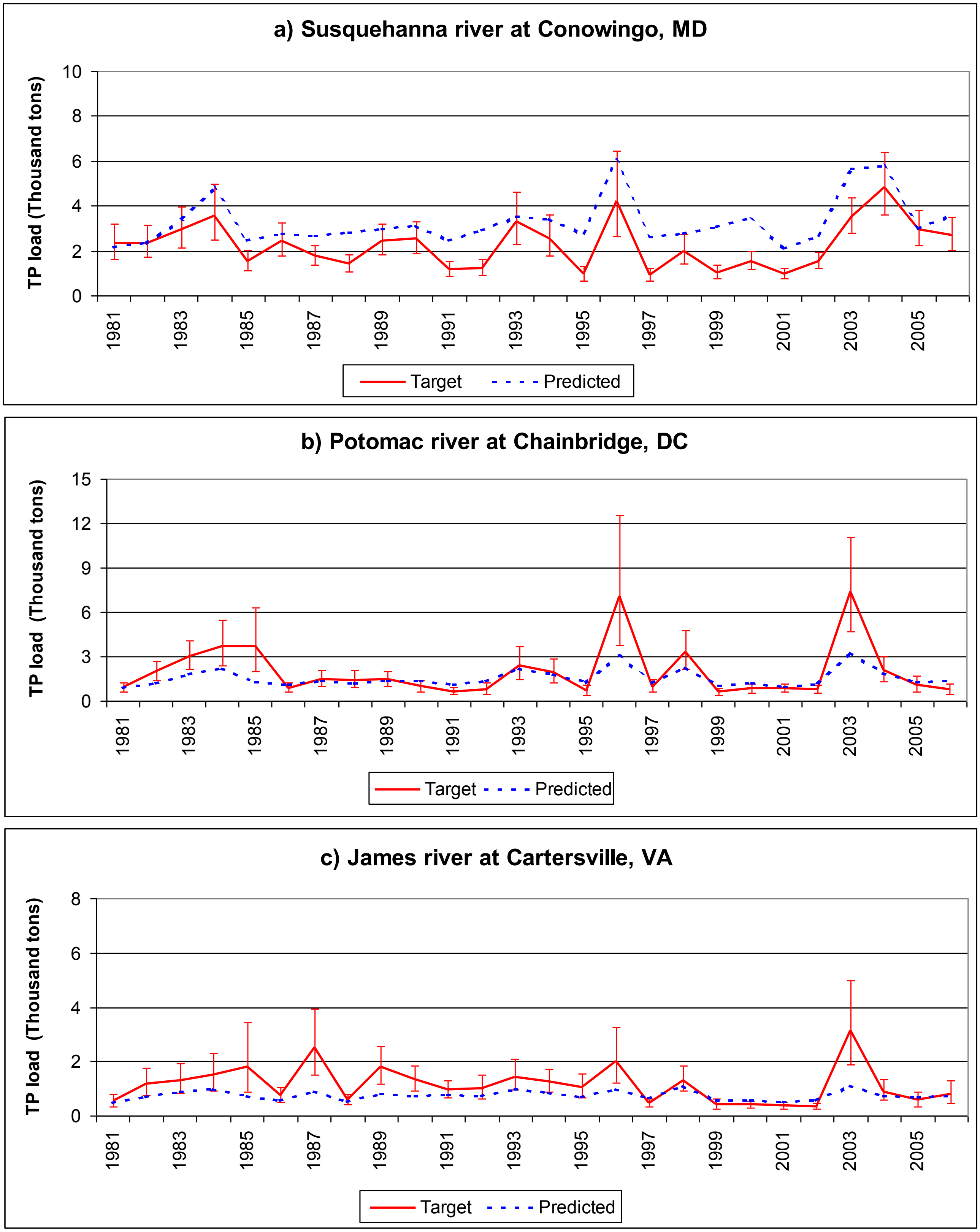

Figure 2-12 Average annual Ortho Phosphate (Ortho P) load for the Upper Mississippi river basin

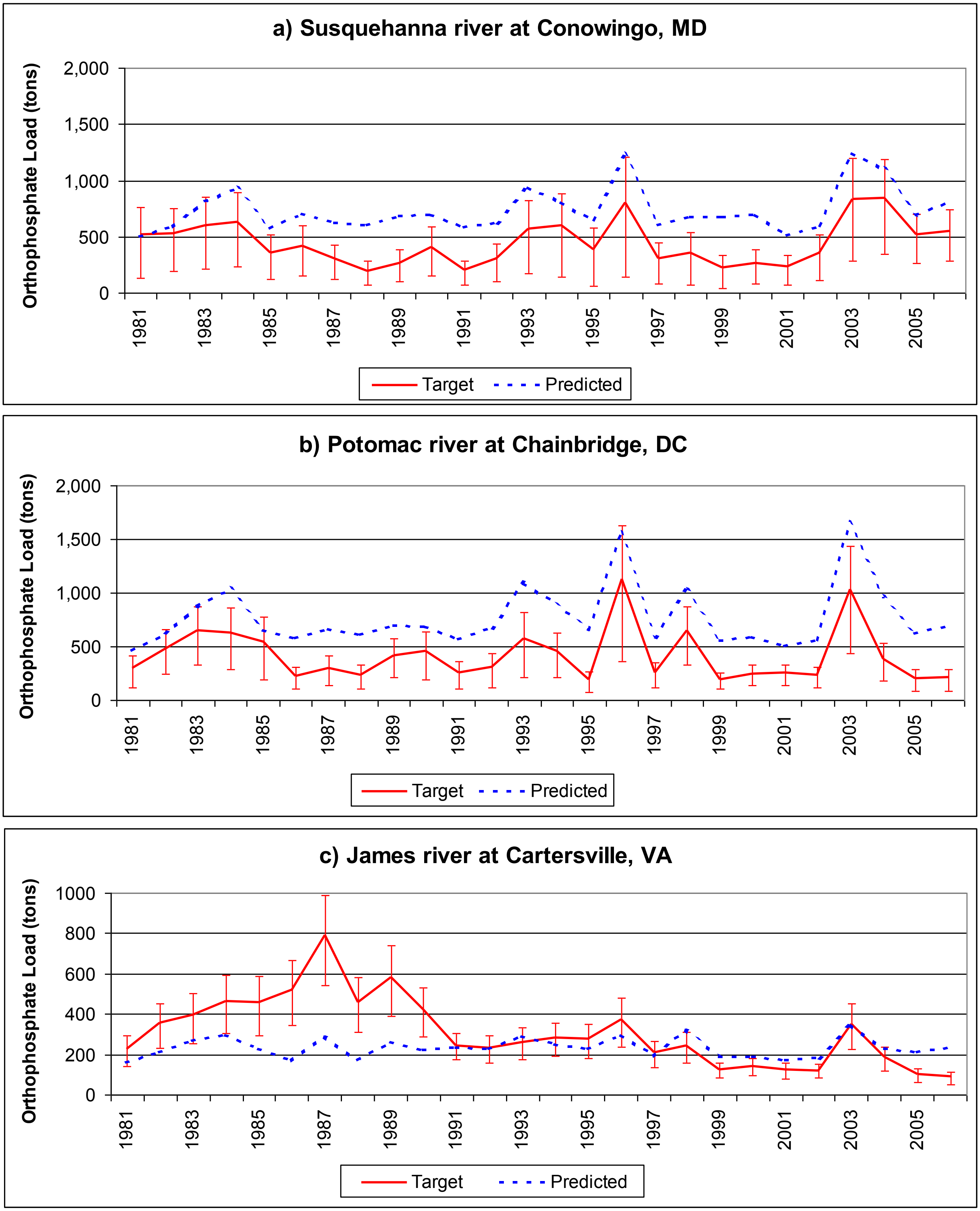

Figure 2-13 Average annual soluble Atrazine load for the Upper Mississippi river basin

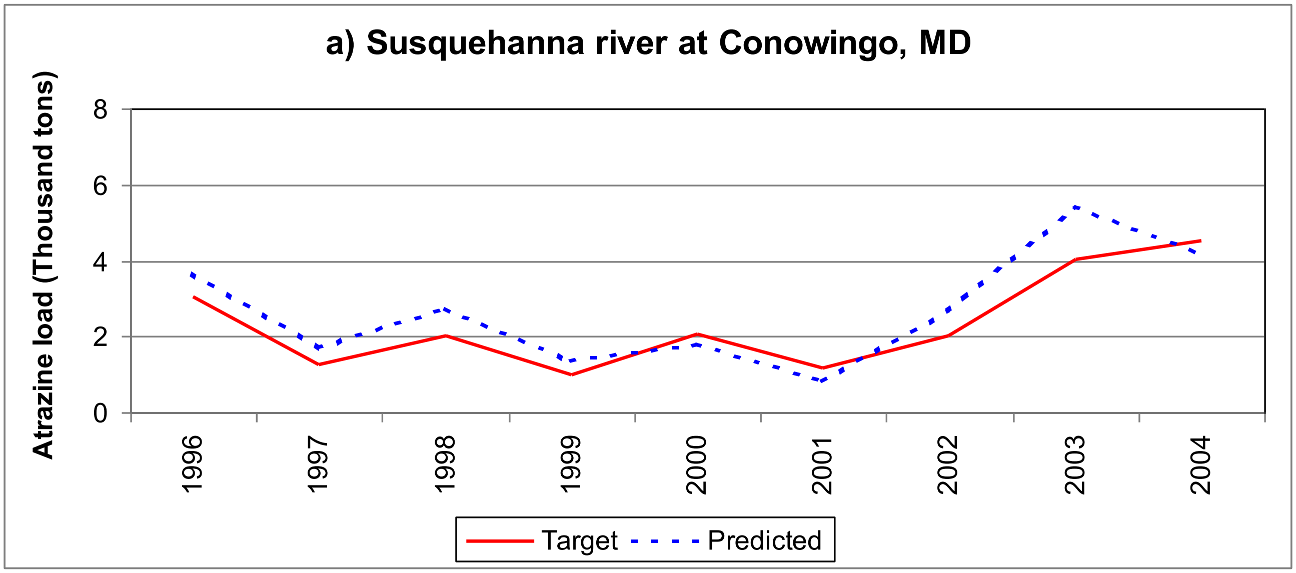

Table 2-6 Average annual Suspended Sediment load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Susquehanna river at Danville, PA	02050107	1,901,391	1,894,771
Susquehanna river at Harrisburg, PA	02050305	3,754,632	3,467,593
Susquehanna river at Conowingo, MD	02050306	1,307,593	1,237,925
Potomac river at Chainbridge, DC	02070008	1,449,681	1,815,891
James river at Cartersville, VA	02080205	883,611	654,744

Table 2-7a Average annual Nitrate and Nitrite Nitrogen load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Susquehanna river at Danville, PA	02050107	------	------
Susquehanna river at Harrisburg, PA	02050305	------	------
Susquehanna river at Conowingo, MD	02050306	44,037	45,440
Potomac river at Chainbridge, DC	02070008	16,311	16,342
James river at Cartersville, VA	02080205	2,357	2,003

Table 2-7b Average annual Total Nitrogen load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Susquehanna river at Danville, PA	02050107	23,502	23,420
Susquehanna river at Harrisburg, PA	02050305	43,996	58,965
Susquehanna river at Conowingo, MD	02050306	58,175	62,871
Potomac river at Chainbridge, DC	02070008	21,824	24,645
James river at Cartersville, VA	02080205	6,622	5,439

Table 2-8a Average annual Total Phosphorus load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Susquehanna river at Danville, PA	02050107	1,821	1,707
Susquehanna river at Harrisburg, PA	02050305	3,279	3,362
Susquehanna river at Conowingo, MD	02050306	1,725	2,256
Potomac river at Chainbridge, DC	02070008	1,506	1,978
James river at Cartersville, VA	02080205	733	1,139

Table 2-8b Average annual Ortho Phosphate load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Susquehanna river at Danville, PA	02050107	------	------
Susquehanna river at Harrisburg, PA	02050305	------	------
Susquehanna river at Conowingo, MD	02050306	380	444
Potomac river at Chainbridge, DC	02070008	768	415
James river at Cartersville, VA	02080205	232	309

Table 2-9 Average annual Atrazine load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Susquehanna river at Danville, PA	02050107	------	------
Susquehanna river at Harrisburg, PA	02050305	------	------
Susquehanna river at Conowingo, MD	02050306	1,749	2,334
Potomac river at Chainbridge, DC	02070008	------	------
James river at Cartersville, VA	02080205	---- --	------

Chapter 3

Calibration and Validation of CEAP-HUMUS for the Delaware River Basin

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Chapter 3 describes results of calibration and validation of CEAP-HUMUS model setup for the Delaware River Basin. More details on procedures used in the calibration-validation process are presented in Chapter 1.

(Status: Complete)

This chapter addresses calibrations of APEX and HUMUS/SWAT for Delaware River Basin (DRB) and to validate the CEAP modeling framework at selected gauging stations. In this report, only the results for rivers that drain to Delaware river will be reported rather than the entire Mid-Atlantic River basin.

Calibration results of the average annual runoff at 8-digit watersheds

Average annual water yield from cultivated and non-cultivated land

The average annual simulated and targeted runoff of the 8-digit watersheds in the Delaware River Basin is shown in Figure 3-2. Targeted and simulated runoff patterns concur with the precipitation patterns of this watershed. The regression relationship between targeted and simulated runoff at 8-digit watersheds (R^2 is 0.47), the means and standard deviations of annual runoff (of all the 8-digit watersheds in the basin) indicate that the model prediction is satisfactory (Figure 3-3 and Table 3-1). All the 8-digit watersheds except 2 were within the stipulated calibration goal of less than 20 % difference between predictions and target values of average annual water yield (Figure 3).

Annual and monthly flow calibration and validation at stream gages

Two USGS stream gages were selected in the DRB for annual and monthly flow calibration and validation (Figure 3-1). Calibration was performed for the period 1961 to 1990 to ensure that there was a reasonable agreement between predicted and observed flow at annual and monthly time steps. The model was validated for annual and monthly flows in the same stream gages for the period 1991 to 2006 without changing the calibrated input parameters.

Flow calibration and validation results at annual and monthly time step are shown in Figures 3-4 to 3-7 and Tables 3-2 to 3-3 for the stream gages located in Delaware river (Montague, NJ and Trenton, NJ).

Observed and simulated flows at annual and monthly time steps matched very well for the calibration period (Figures 3-4 and 3-5). Means and standard deviations of predictions and observations are in close agreement (Table 3-2). In addition, the coefficient of determination is greater than 0.6 (R^2) and NSE is greater than 0.5 (Table 3-3) for both the gauges.

In summary, during calibration period, the model performance evaluation measures suggest an overall good agreement between observed and simulated flows at the annual and monthly time step, throughout the river basin.

Annual and monthly flow results for the above listed gauging stations for validation period are shown in (Figure 3-6, and 3-7 and Table 3-3). Based on R^2 and NSE it can be seen that all the gauges show acceptable predicted results from model. In summary, HUMUS-SWAT is able to capture the annual and monthly flow patterns very well in the Delaware River Basin.

Sediment calibration

Predicted sediment results were validated in 2 different gauging stations (Figure 3-1) in the DRB as outlined in Table 3-4. Detailed results are shown only for one location because the second location has frequent data gaps. However, the means are shown for both the stations (Table 3-4). Figure 3-8 shows a detailed comparison of predicted and target sediment loads in Delaware river at Trenton, NJ. In general, there is over-estimation (Table 3-4, Figure 3-8) of annual sediment load in both the locations. However, there is close match between predictions and target values of sediment load (Figure 3-8, Table 3-4). Confidence limits were not available to make any further judgment on the predicted sediment loads. Considering the quality of predicted sediment loads in both the places of validation, we could say the model results are good enough for making scenario trials.

Nutrient Calibration

Predicted nutrient results were validated in two gauging stations (Figure 3-1) in DRB as outlined in Tables 3-5, and Table 3-6. Detailed results are shown only for one location because the second location has frequent data gaps. However, the predicted and target means are shown for both the stations (Table 3-5 and Table 3-6). Figures 3-9 and 3-10 show a detailed comparison of predicted and target nutrient loads for Delaware river at Trenton, NJ. Confidence limits were not available to make any further judgment on the predicted nutrient loads. In general, the predicted nutrient loads from HUMUS-SWAT are in good agreement with the target values suggesting the suitability of the model for making scenario trials.

Atrazine calibration

For this river basin, the availability of atrazine observations was limited to one gauge only. Therefore, predicted atrazine results were validated in that gauge as outlined in Table 3-7, and Figure 3-11. Figure 3-11 shows a detailed comparison of predicted and target atrazine loads in Delaware river at Trenton, NJ. In general, the pattern/trend and magnitude of predicted atrazine loads from HUMUS-SWAT are in agreement with the target values. However, the predicted atrazine loads are over-estimated. The over-estimation can be attributed to uncertainties in observations, and the procedure used to obtain annual loads from daily grab samples.

Figure 3-1 Location of the Delaware River basin and sampling locations

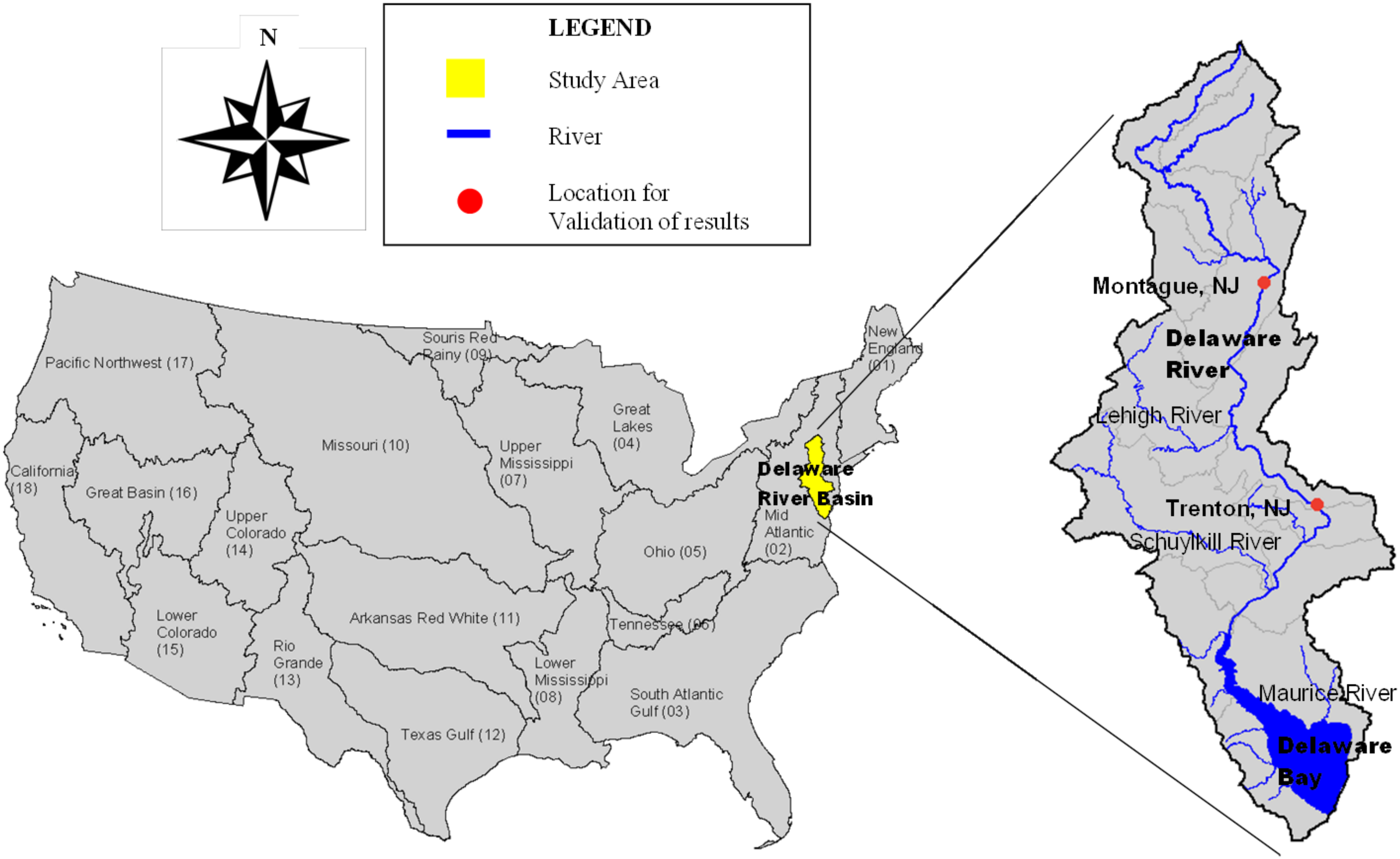


Figure 3-2 Average annual water yield of all 8-digit watersheds in the Delaware River basin from cultivated and non-cultivated area (combined water yield from APEX and SWAT)

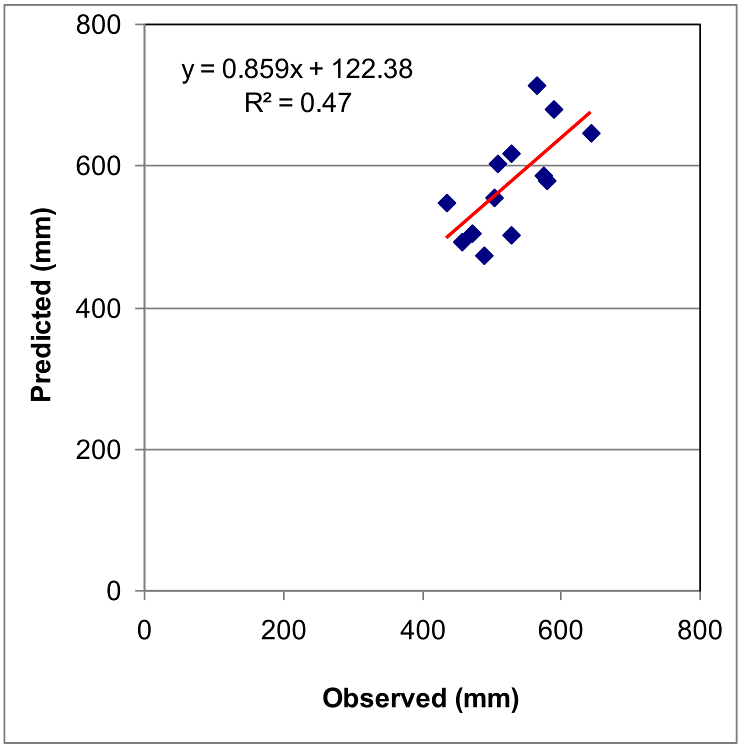


Figure 3-3 Percentage difference between predictions and observations of annual average flow in the DRB (combined water yield from APEX and SWAT after calibration

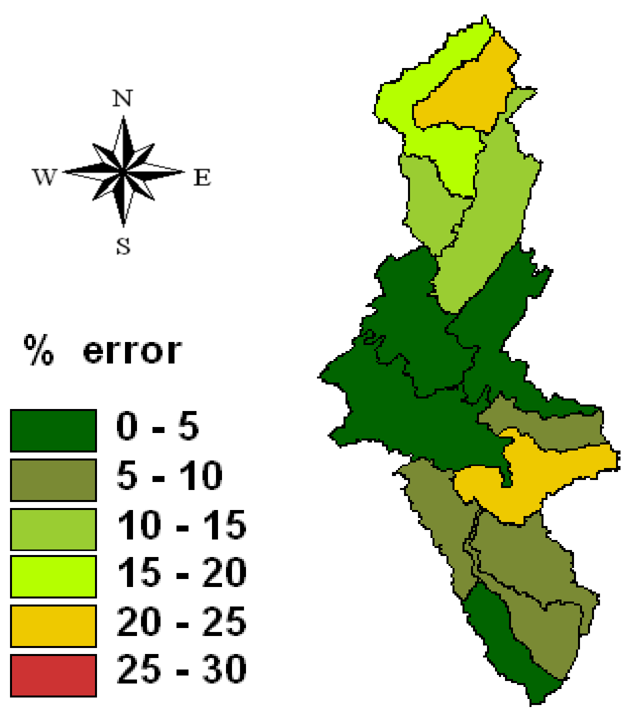


Table 3-1 Basin-average statistics for predicted and target annual water yield for all 8-digit watersheds in the Delaware River basin —Combined water yield results from APEX and SWAT after calibration (1961–90)

Calibration	Statistic	Value
Predictions (After calibration)	Mean (mm) Standard deviation (mm)	529.1 59.5
Observations	Mean (mm) Standard deviation (mm)	576.9 74.3

Figure 3-4 Average annual stream flow for the Delaware river basin-Calibration period

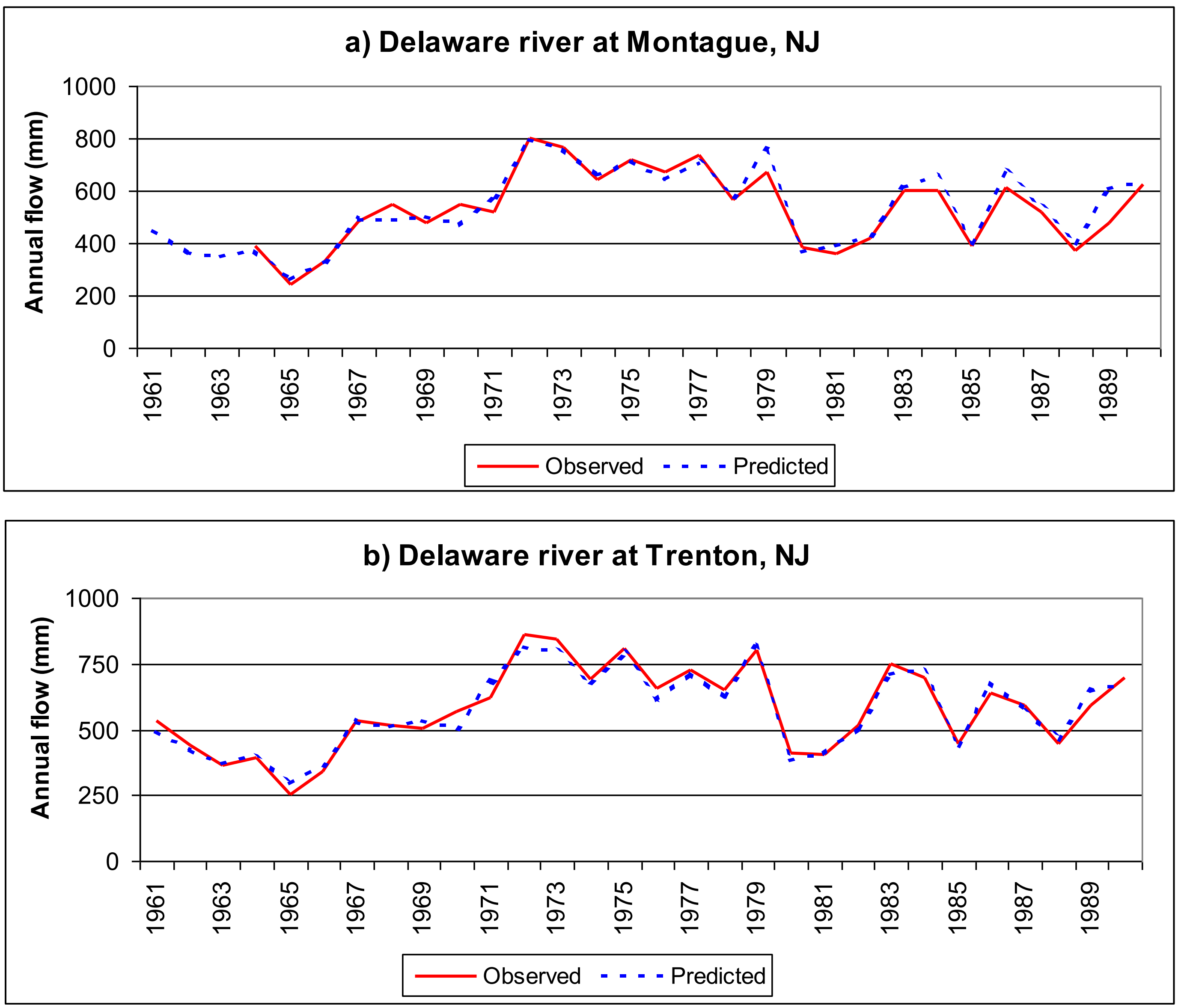


Figure 3-5 Average monthly stream flow for the Delaware river basin-Calibration period

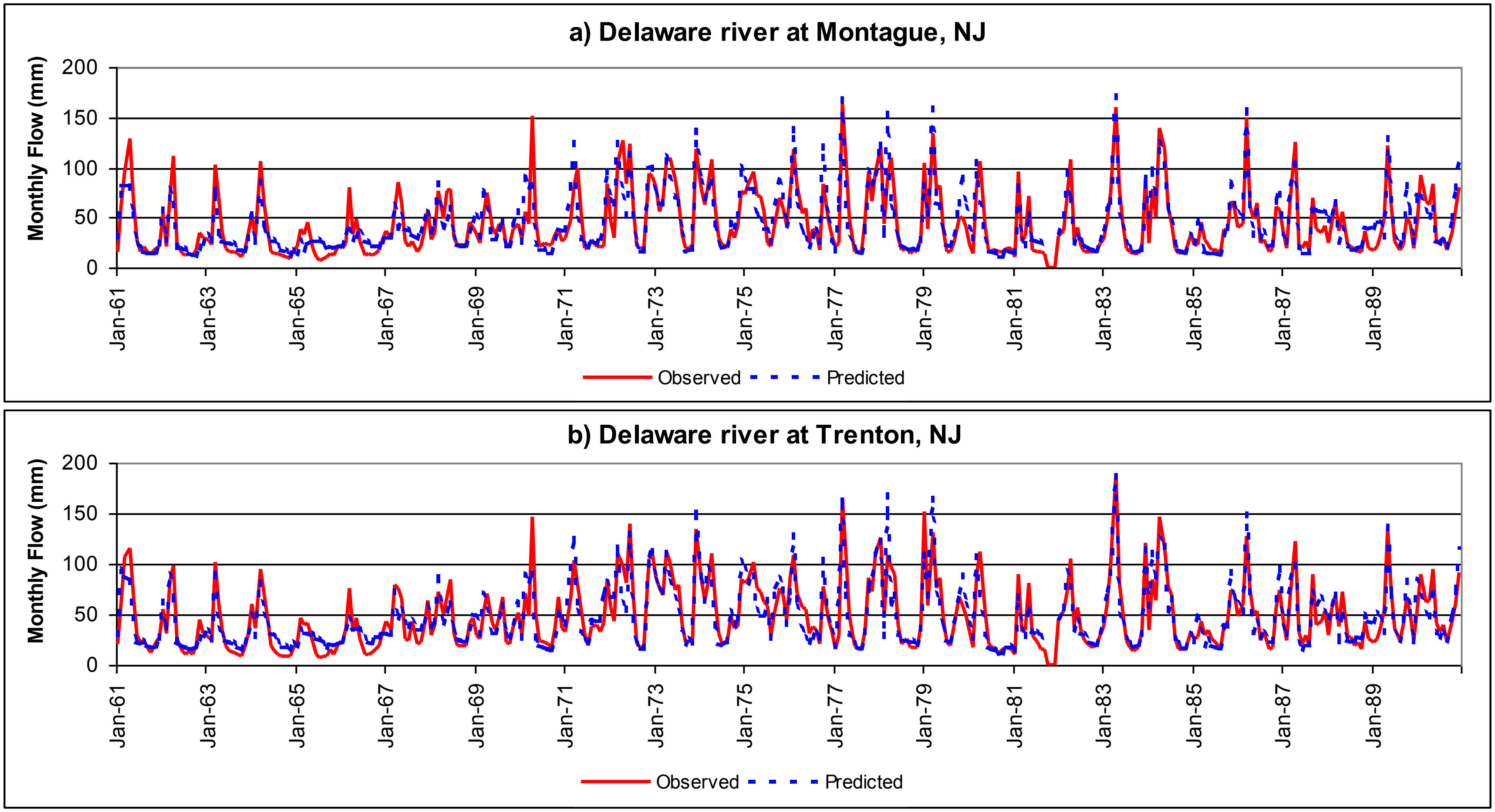


Figure 3-6 Average annual stream flow for the Delaware river basin-Validation period

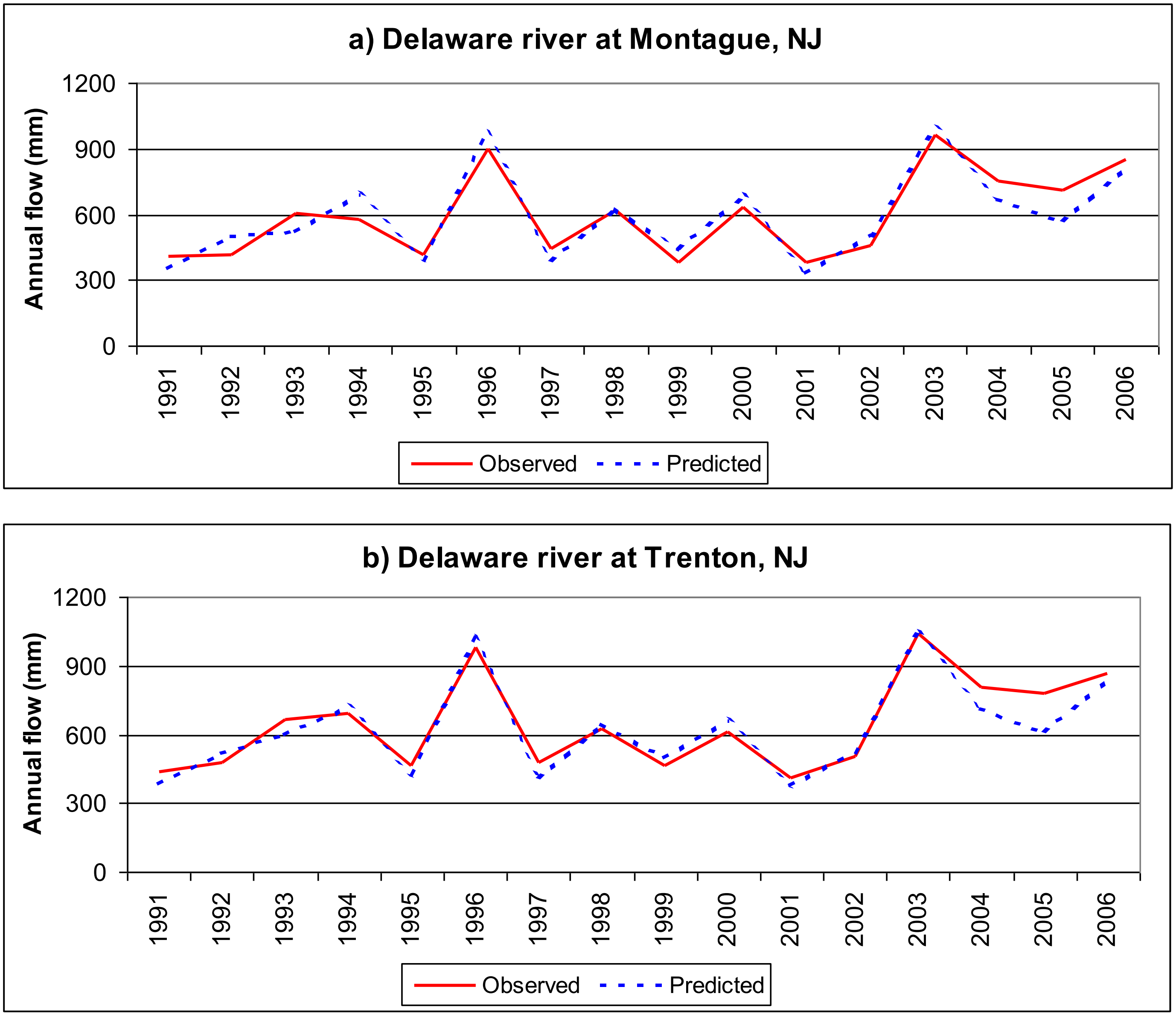
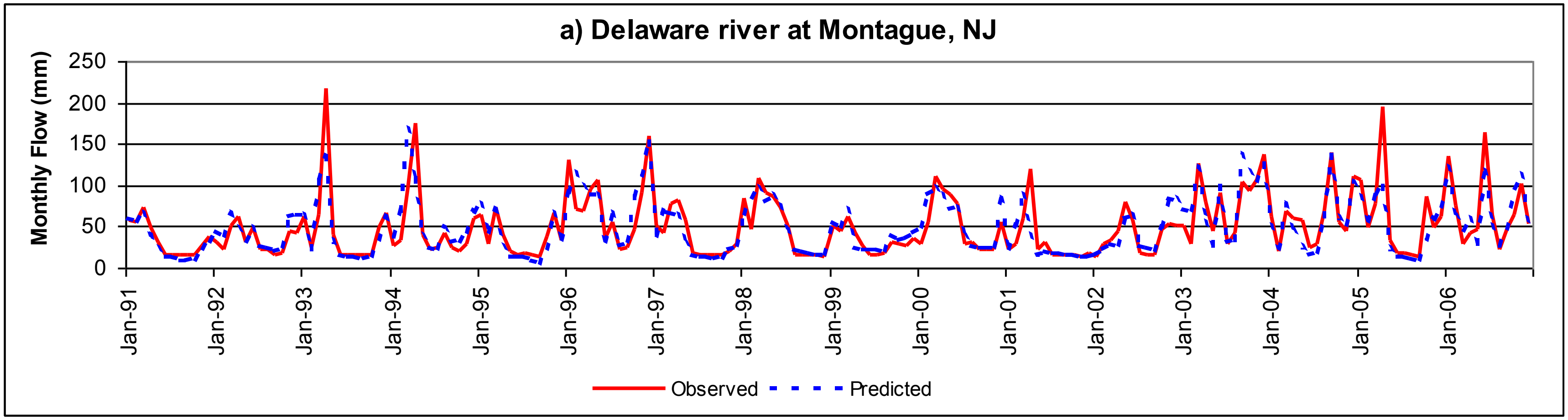


Figure 3-7 Average monthly stream flow for the Delaware river basin-Validation period



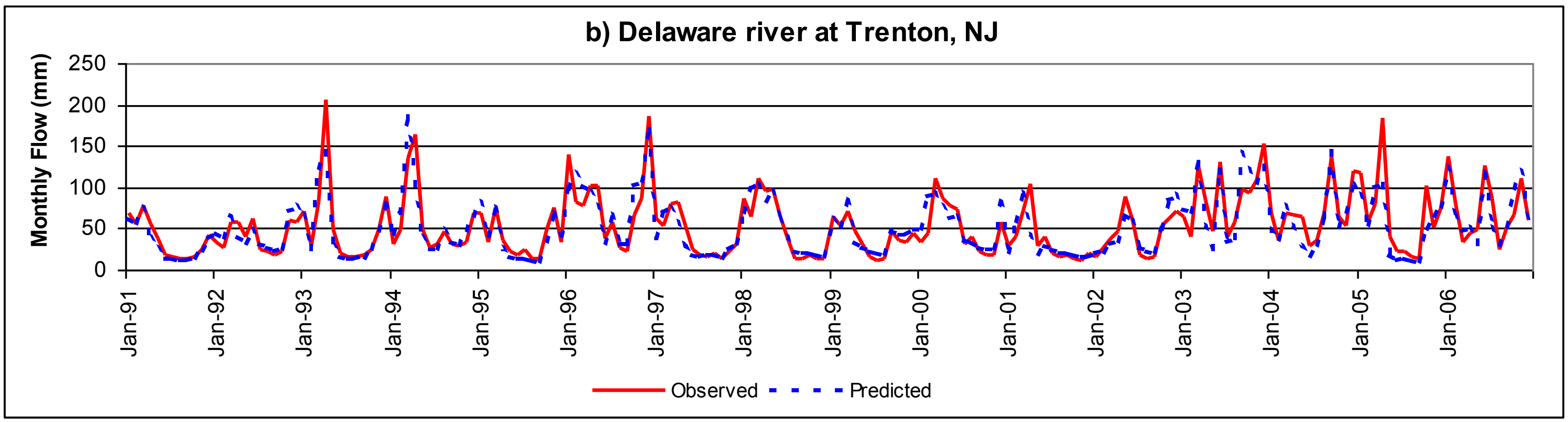


Table 3-2 Model performance evaluation for annual and monthly stream flow at selected gauging stations for the calibration period (1961-1990)

	Montague, NJ	**Trenton, NJ**
Gauge details		
River	Delaware river	Delaware river
River reach-HUC	02040104	02040105
Drainage area (Km^2)	9,013.2	17,560.1
Data availability (period)	1961-1990	1961-1990
Mean flow (mm)		
Annual-Predictions	532.0	570.1
Annual-Observations	535.3	575.1
Monthly-Predictions	44.4	47.7
Monthly-Observations	43.6	47.7
Standard deviation (mm)		
Annual-Predictions	147.6	151.2
Annual-Observations	144.7	158.8
Monthly-Predictions	30.9	31.8
Monthly-Observations	32.0	32.8
R^2		
Annual	0.92	0.96
Monthly	0.76	0.81
Nash and Sutcliffe Efficiency		
Annual	0.91	0.96
Monthly	0.75	0.81

Table 3-3 Model performance evaluation for annual and monthly stream flow at selected gauging stations for the validation period (1991-2006)

	Montague, NJ	**Trenton, NJ**
Gauge details		
River	Delaware river	Delaware river
River reach-HUC	02040104	02040105
Drainage area (Km^2)	9,013.2	17,560.1
Data availability (period)	1961-1990	1961-1990
Mean flow (mm)		
Annual-Predictions	589.7	620.6
Annual-Observations	592.0	642.9
Monthly-Predictions	49.1	51.8
Monthly-Observations	49.4	53.6
Standard deviation (mm)		
Annual-Predictions	206.7	206.5
Annual-Observations	194.5	201.4
Monthly-Predictions	34.1	35.4
Monthly-Observations	37.1	37.4
R^2		
Annual	0.87	0.91
Monthly	0.73	0.78
Nash and Sutcliffe Efficiency		
Annual	0.86	0.89
Monthly	0.72	0.77

Figure 3-8 Average annual sediment loads for Delaware river basin

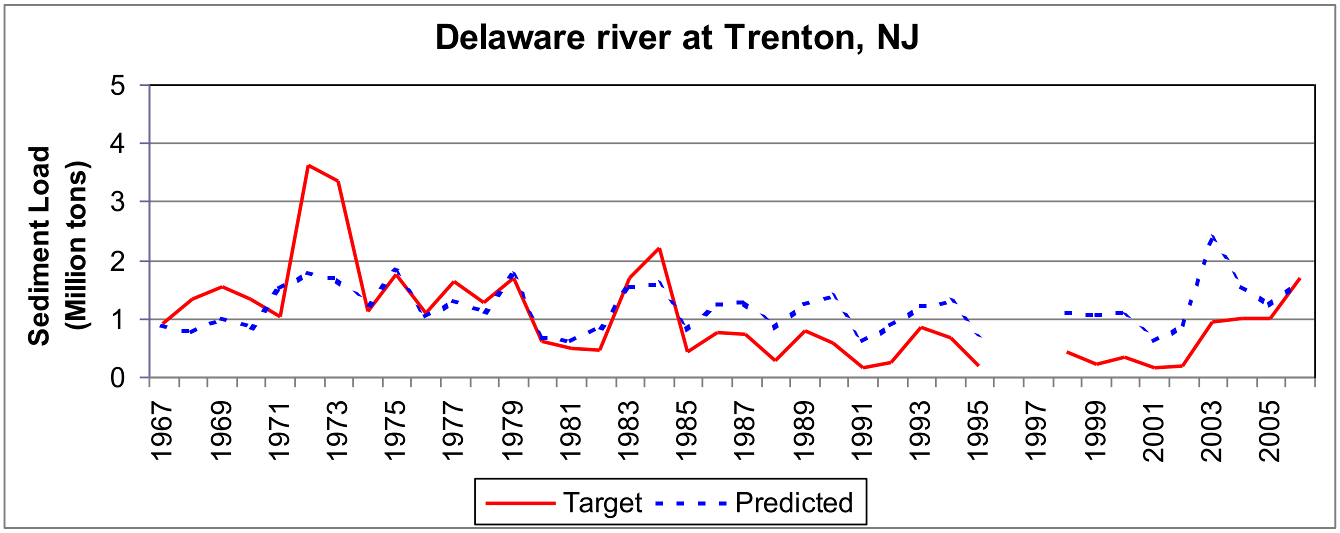


Figure 3-9 Average annual total Nitrogen (TN) load for the Delaware river basin

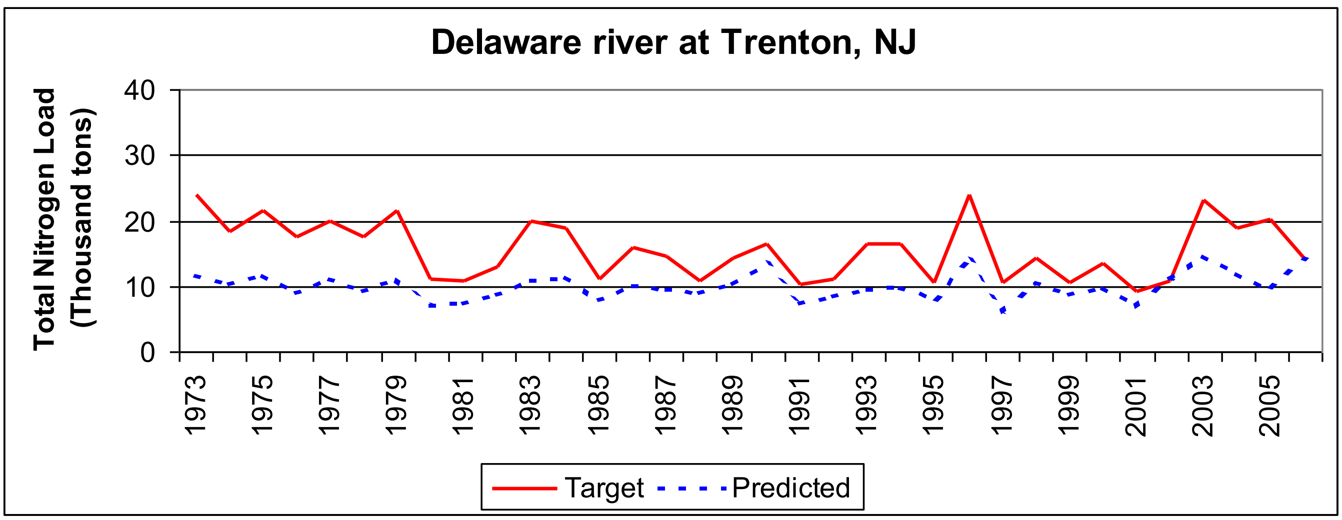


Figure 3-10 Average annual total Phosphorus (TP) load for the Delaware river basin

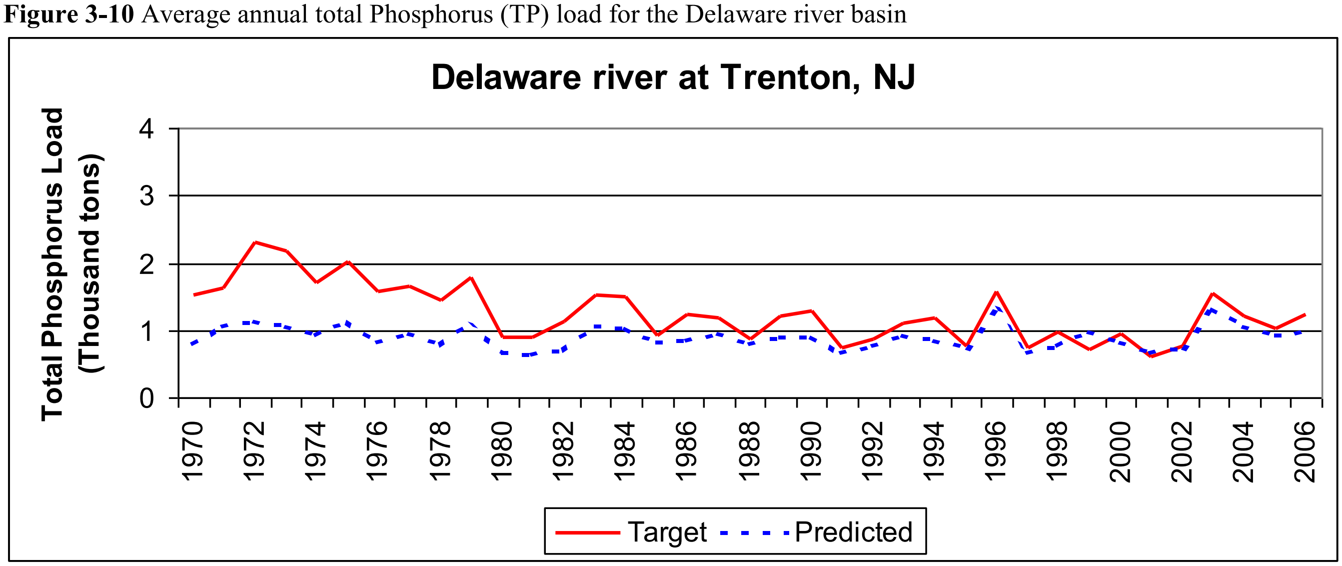


Figure 3-11 Average annual soluble Atrazine load for the Delaware river basin

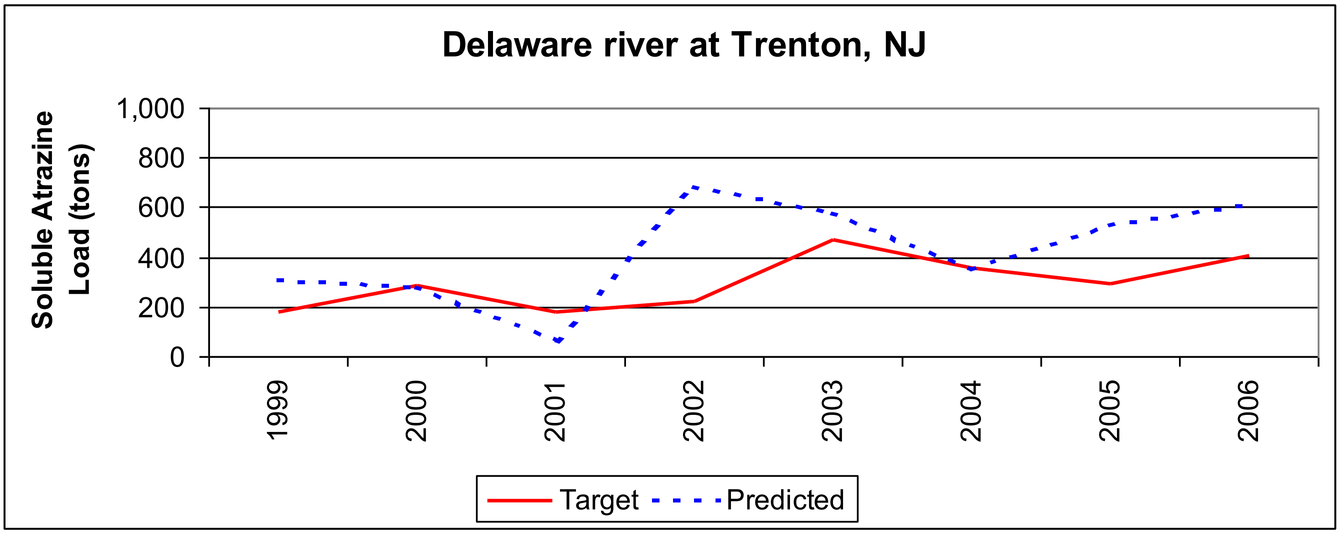


Table 3-4 Average annual Suspended Sediment load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Delaware river at Montague, NJ	02040104	46,050	41,040
Delaware river at Trenton, NJ	02040105	1,175,603	1,015,516

Table 3-5 Average annual Total Nitrogen load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Delaware river at Montague, NJ	02040104	3,207	2,621
Delaware river at Trenton, NJ	02040105	9,901	15,539

Table 3-6 Average annual Total Phosphorus load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Delaware river at Montague, NJ	02040104	195	172
Delaware river at Trenton, NJ	02040105	887	1,249

Table 3-7 Average annual Atrazine load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Delaware river at Trenton, NJ	02040105	423	296

Chapter 4

Calibration and Validation of CEAP-HUMUS for the Tennessee River Basin

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Chapter 4 describes results of calibration and validation of CEAP-HUMUS model setup for the Tennessee River Basin. More details on procedures used in the calibration-validation process are presented in Chapter 1.

(Status: Complete)

This chapter addresses calibrations of APEX and HUMUS/SWAT for the Tennessee River Basin (TRB) and to validate the CEAP modeling framework at selected gauging stations.

Calibration results of the average annual runoff at 8-digit watersheds

Average annual water yield from cultivated and non-cultivated land

The average annual simulated and targeted runoff of the 8-digit watersheds in the Tennessee River basin is shown in Figure 4-2. Targeted and simulated runoff patterns concur with the precipitation patterns of this watershed. The regression relationship between targeted and simulated runoff at 8-digit watersheds (R^2 is 0.77), the means and standard deviations of annual runoff (of all the 8-digit watersheds in the basin) indicate that the model prediction is satisfactory (Figure 4-3 and Table 4-1). All the 8-digit watersheds except 2 were within the stipulated calibration goal of less than 20% difference between predictions and target values of average annual water yield (Figure 3).

Annual and monthly flow calibration and validation at stream gages

Two USGS stream gages were selected in the TRB for annual and monthly flow calibration and validation (Figure 4-1). Calibration was performed for the period 1961 to 1990 to ensure that there was a reasonable agreement between predicted and observed flow at annual and monthly time steps. The model was validated for annual and monthly flows in the same stream gages for the period 1991 to 2006 without changing the calibrated input parameters. Tennessee River and its tributaries are impounded by several reservoirs throughout the basin. To improve the simulated flow and water quality results from the model setup, observed mean reservoir outflow data at monthly time step were read into the model.

Flow calibration and validation results at annual and monthly time step are shown in Figures 4-4 to 4-7 and Tables 4-2 to 4-5 for the stream gages located in Tennessee River (Whitesburg, AL and Savannah, TN).

Observed and simulated flows at annual and monthly time steps matched very well for the calibration period (Figures 4-4 and 4-5). Means and standard deviations of predictions and observations are in close agreement (Table 4-2). In addition, the coefficient of determination is greater than 0.6 (R^2) and NSE is greater than 0.5 (Table 4-3) for all the gauges during the calibration period. In summary, during calibration period, the model performance evaluation measures suggest an overall good agreement between observed and simulated flows at the annual and monthly time step, throughout the river basin.

Annual and monthly flow results for the above listed gauging stations for validation period are shown in (Figures 4-6 and 4-7 and Tables 4-4 and 4-5). Based on the R^2 and NSE values it can be seen that all the gauges show acceptable predicted results from model. In summary, HUMUS-SWAT is able to capture the annual and monthly flow patterns very well in the Tennessee River basin.

Sediment calibration

Predicted sediment results were validated in 4 different gauging stations (Figure 4-1) in TRB as outlined in Table 4-6. To limit the contents of this section, detailed results are shown only for three locations. However, the means are shown for all stations (Table 4-6). Figure 4-8 shows a detailed comparison of predicted and target sediment loads in Tennessee River at Wattsbar dam, TN, South Pittsburgh, TN, and Savannah, TN (Table 4-6, Figure 4-8) of annual sediment loads. For all the gauging stations analyzed, there is close match between predictions and target values of sediment load (Figure 4-8). However, there is under-estimation of sediment in Savannah, TN and Paducah, TN. The possible reasons are: 1) Under estimation of flow, 2) modeled sediment deposition in the reaches and reservoirs is high. However, considering the quality of predicted sediment loads in all the places of validation, we could say the model results are good enough for making scenario trials.

Nutrient Calibration

Predicted nutrient results were validated in four gauging stations (Figure 4-1) in TRB as outlined in Tables 4-7, and Table 4-8. Because the availability of nutrient observations is limited, the modeled results are compared with observations in all the places of data availability. The predicted and target means are shown for all the stations (Table 4-7 and Table 4-8). Figures 4-9 through 4-14 show a detailed comparison of predicted and target nutrient loads (various constituents of N and P) in Tennessee River at Wattsbar dam, TN, South Pittsburgh, TN, and Savannah, TN and near Paducah, KY. Error bars or the upper and lower confidence levels of target values are also presented. In general, the predicted nutrient loads from HUMUS-SWAT are in good agreement with the target values and within the uncertainty limits of target values for all the nutrient constituent-location combinations (except NH_3 nitrogen near Paducah, KY and total Phosphorus at South Pittsburgh, TN). The over-estimation of NH_3 nitrogen near Paducah can possibly come from over-estimation of NH_3 nitrogen in upstream reaches, uncertainties in point source data and uncertainty in NH_3 N observations used for validation .

The possible reasons for over estimation of total phosphorus at South Pittsburgh, TN could be a) over-estimation of sediment in many upstream reaches, and b) uncertainties in observations. It should be noted that the daily total phosphorus loads were estimated from limited grab samples and compared with modeled daily TP loads that are uncertain.

Atrazine calibration

For this river basin, the availability of atrazine observations was limited to one gauge only. Therefore, predicted atrazine results were validated in that gauge as outlined in Table F-9, and Figure 4-15. Figure 4-15 shows a detailed comparison of predicted and target atrazine loads in Tennessee River near Paducah, KY. In general, the pattern/trend and magnitude of predicted atrazine loads from HUMUS-SWAT are in agreement with the target values. However, the predicted atrazine loads are under-estimated. The under-estimation can be attributed to uncertainties in observations, procedure used to obtain annual loads from daily grab samples.

Table 4-1 Basin-average statistics for predicted and target annual water yield for all 8-digit watersheds in the CB watershed — Combined water yield results from APEX and SWAT after calibration (1961–90)

Calibration	Statistic	Value
Predictions (After calibration)	Mean (mm)	620.4
	Standard deviation (mm)	123.1
Observations	Mean (mm)	650.0
	Standard deviation (mm)	146.6

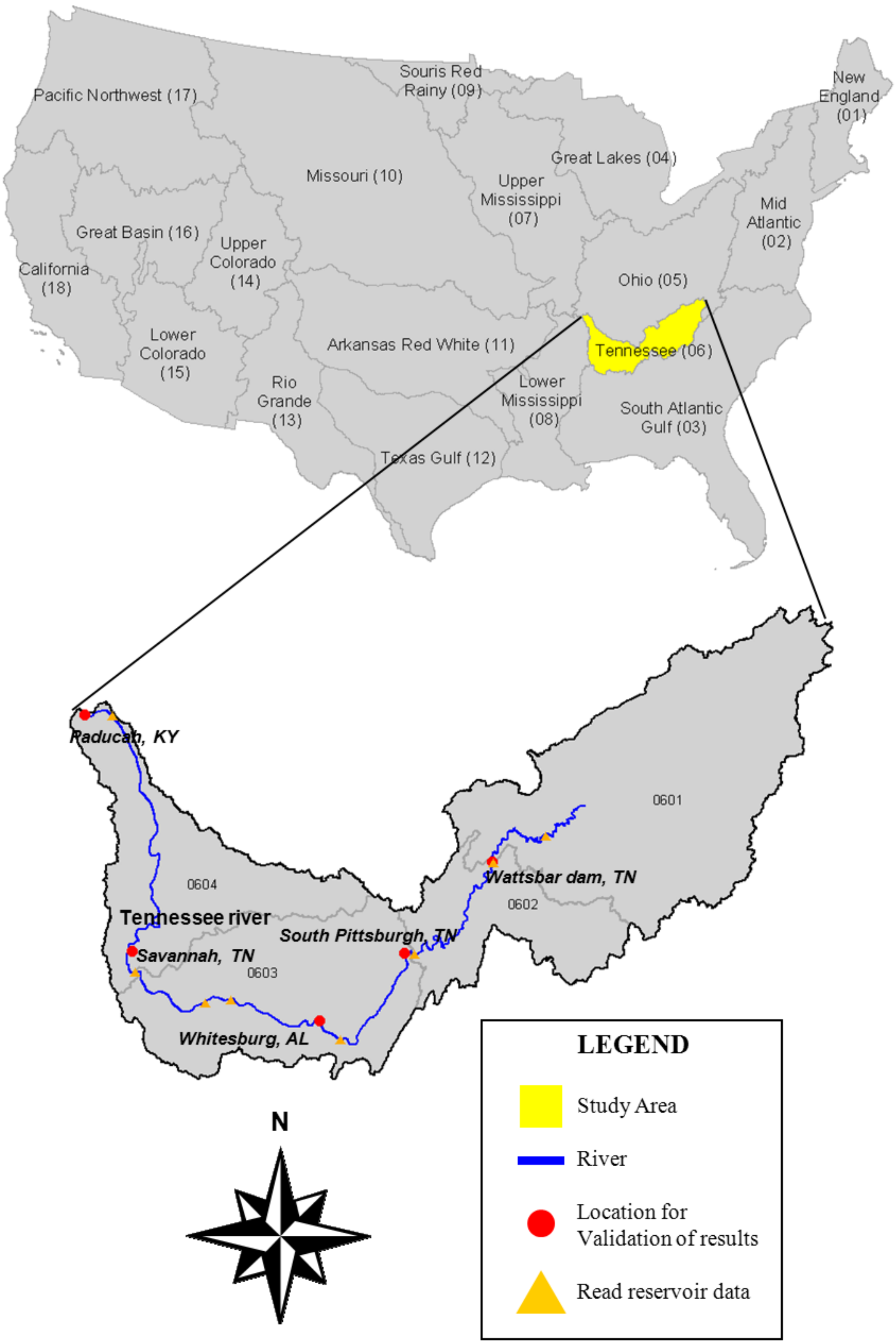


Figure 4-1 Location of the Tennessee River basin and sampling locations

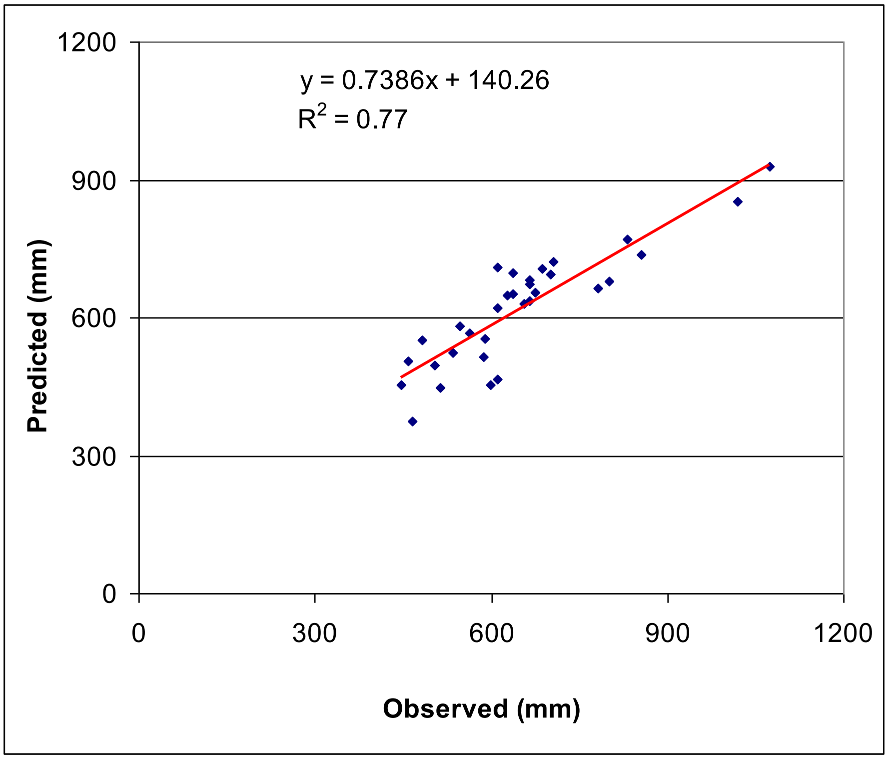


Figure 4-2 Average annual water yield of all 8-digit watersheds in the Tennessee River basin from cultivated and non-cultivated area (combined water yield from APEX and SWAT)

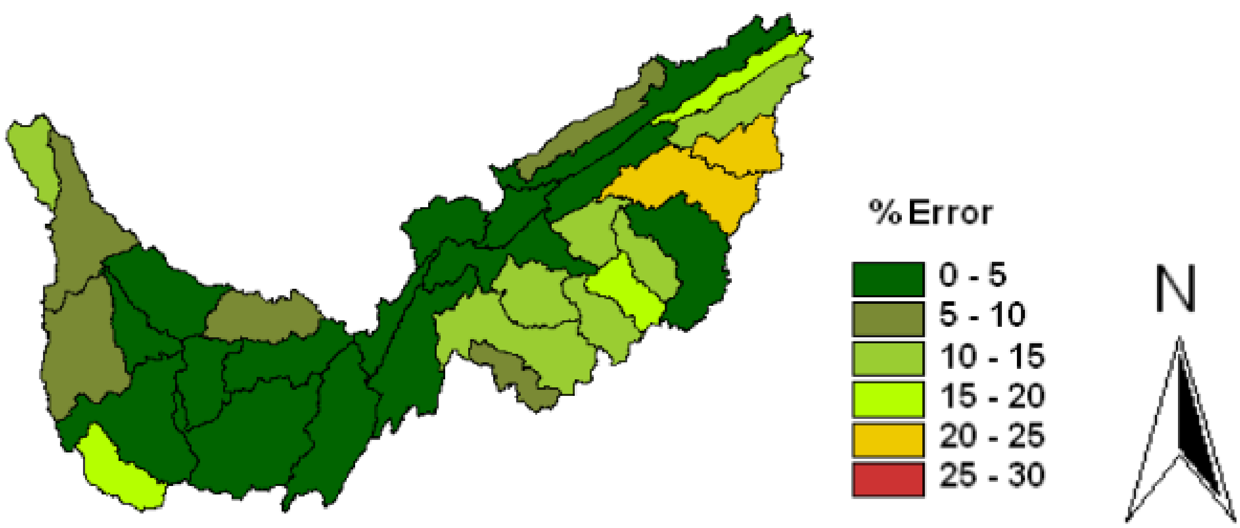


Figure 4-3 Percentage difference between predictions and observations of annual average flow in the TRB (combined water yield from APEX and SWAT after calibration)

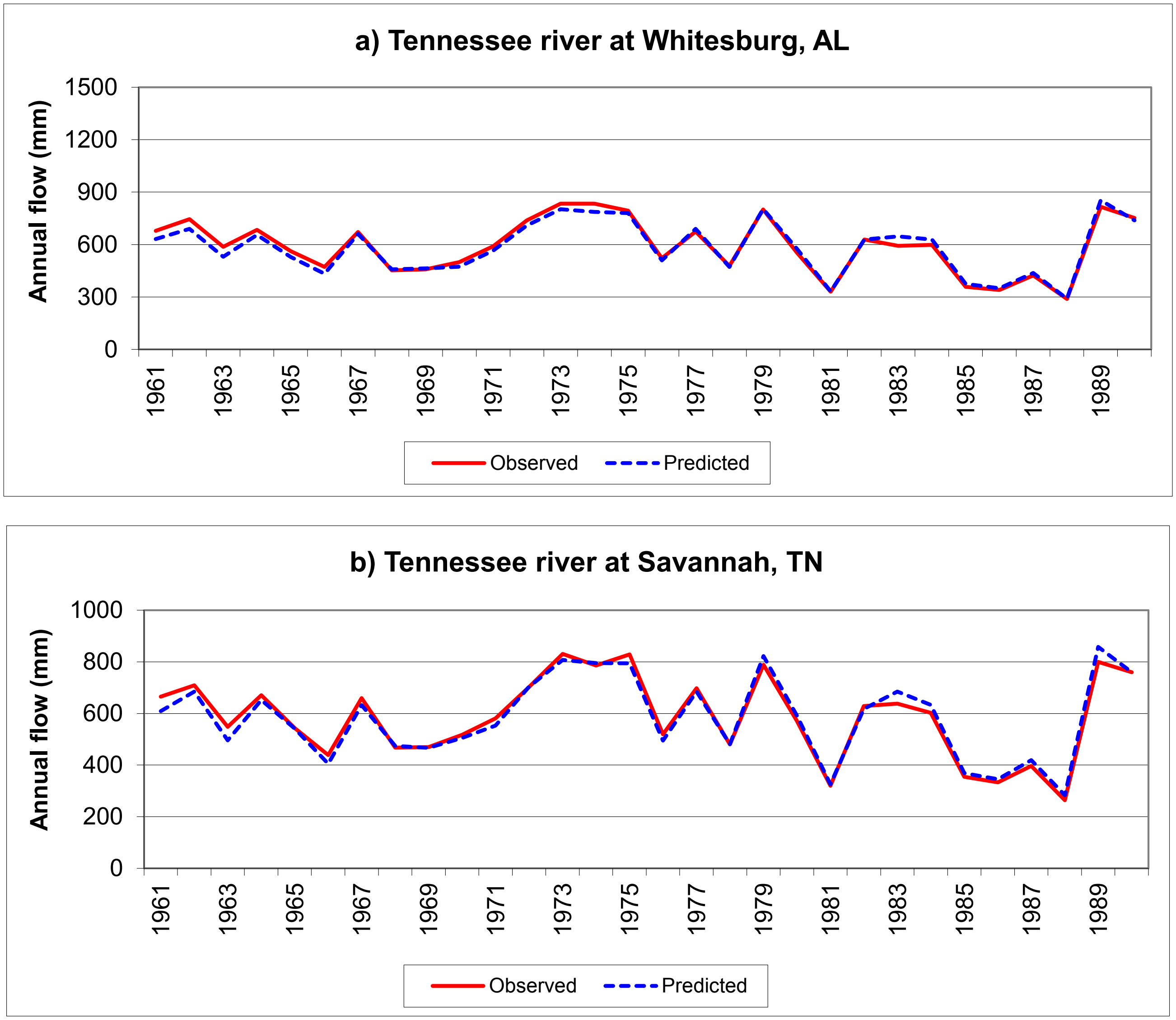
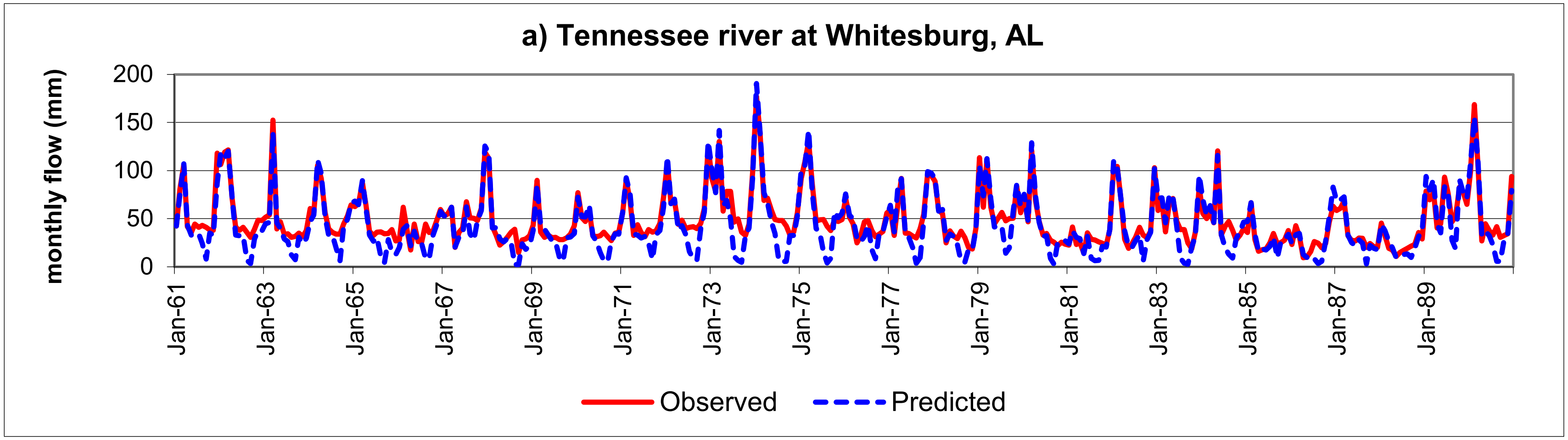


Figure 4-4 Average annual stream flow for the Tennessee River basin-Calibration period



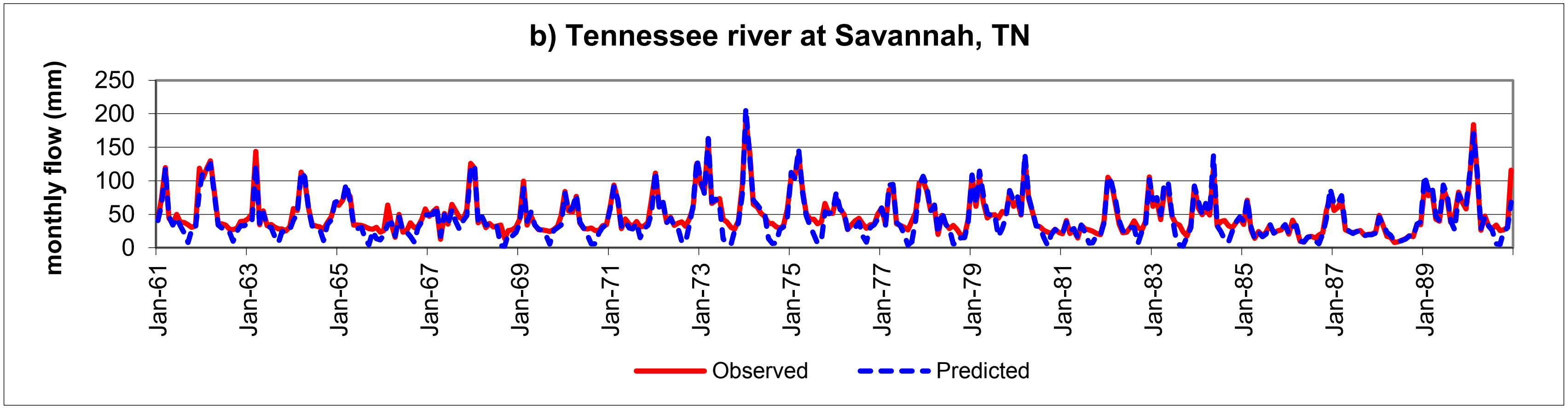


Figure 4-5 Average monthly stream flow for the Tennessee River basin-Calibration period

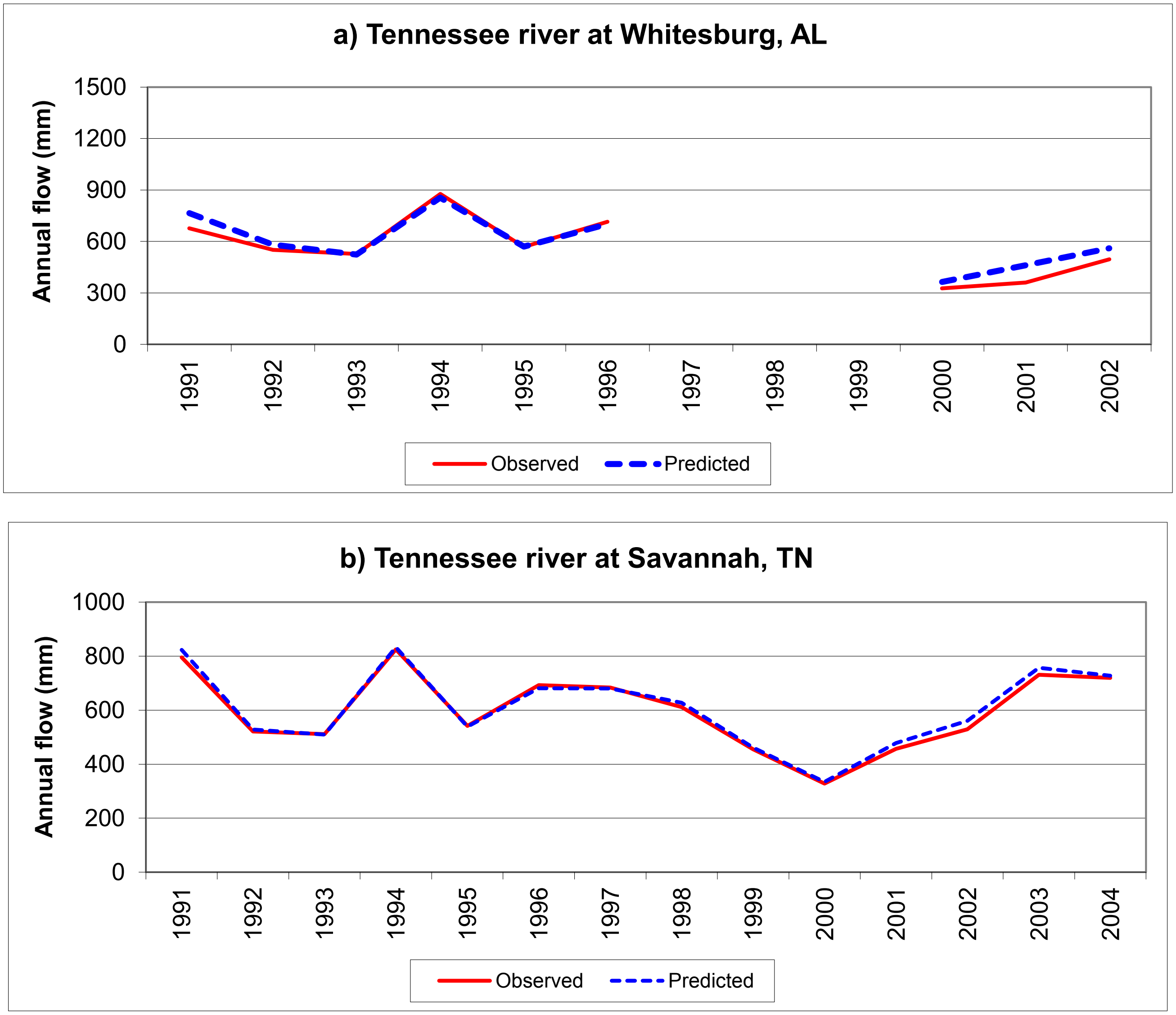


Figure 4-6 Average annual stream flow for the Tennessee River basin-Validation period

Table 4-2 Mean and standard deviation of the predicted and observed annual and monthly stream flow at selected gauging stations for the calibration period (1961-1990)

	Whitesburg, AL	Savannah, TN
Gauge details		
River	Tennessee River	Tennessee River
River reach-HUC	06030002	06040001
Drainage area (Km^2)	66,329.6	85,832.0
Data availability (period)	1961-1990	1961-1990
Mean flow (mm)		
Annual-Predictions	583.1	582.9
Annual-Observations	591.7	585.6
Monthly-Predictions	43.1	44.2
Monthly-Observations	48.7	48.2
Standard deviation (mm)		
Annual-Predictions	154.2	159.6
Annual-Observations	159.8	160.0
Monthly-Predictions	32.0	33.0
Monthly-Observations	27.2	29.6

Table 4-3 Coefficient of determination and efficiency of the predicted and observed annual and monthly stream flow at selected gauging stations for the calibration period (1961-1990)

	Whitesburg, AL	Savannah, TN
Gauge details		
River	Tennessee River	Tennessee River
River reach-HUC	06030002	06040001
Drainage area (Km^2)	66,329.6	85,832.0
Data availability (period)	1961-1990	1961-1990
R^2		
Annual	0.97	0.97
Monthly	0.86	0.93
Nash and Sutcliffe Efficiency		
Annual	0.76	0.97
Monthly	0.95	0.91

Table 4-4 Mean and standard deviation of the predicted and observed annual and monthly stream flow at selected gauging stations for the validation period (1991-2006)

	Whitesburg, AL	Savannah, TN
Gauge details		
River	Tennessee River	Tennessee River
River reach-HUC	06030002	06040001
Drainage area (Km^2)	66,329.6	85,832.0
Data availability (period)	1991-1996, 2000-2002	1991-2004
Mean flow (mm)		
Annual-Predictions	576.4	610.1
Annual-Observations	552.8	600.2
Monthly-Predictions	46.8	47.7
Monthly-Observations	49.2	49.0
Standard deviation (mm)		
Annual-Predictions	160.8	146.9
Annual-Observations	193.1	145.0
Monthly-Predictions	32.7	31.6
Monthly-Observations	29.2	30.1

Table 4-5 Coefficient of determination and efficiency of the predicted and observed annual and monthly stream flow at selected gauging stations for the validation period (1991-2006)

	Whitesburg, AL	Savannah, TN
Gauge details		
River	Tennessee River	Tennessee River
River reach-HUC	06030002	06040001
Drainage area (Km^2)	66,329.6	85,832.0
Data availability (period)	1991-1996, 2000-2002	1991-2004
R^2		
Annual	0.94	0.99
Monthly	0.85	0.97
Nash and Sutcliffe Efficiency		
Annual	0.93	0.99
Monthly	0.80	0.90

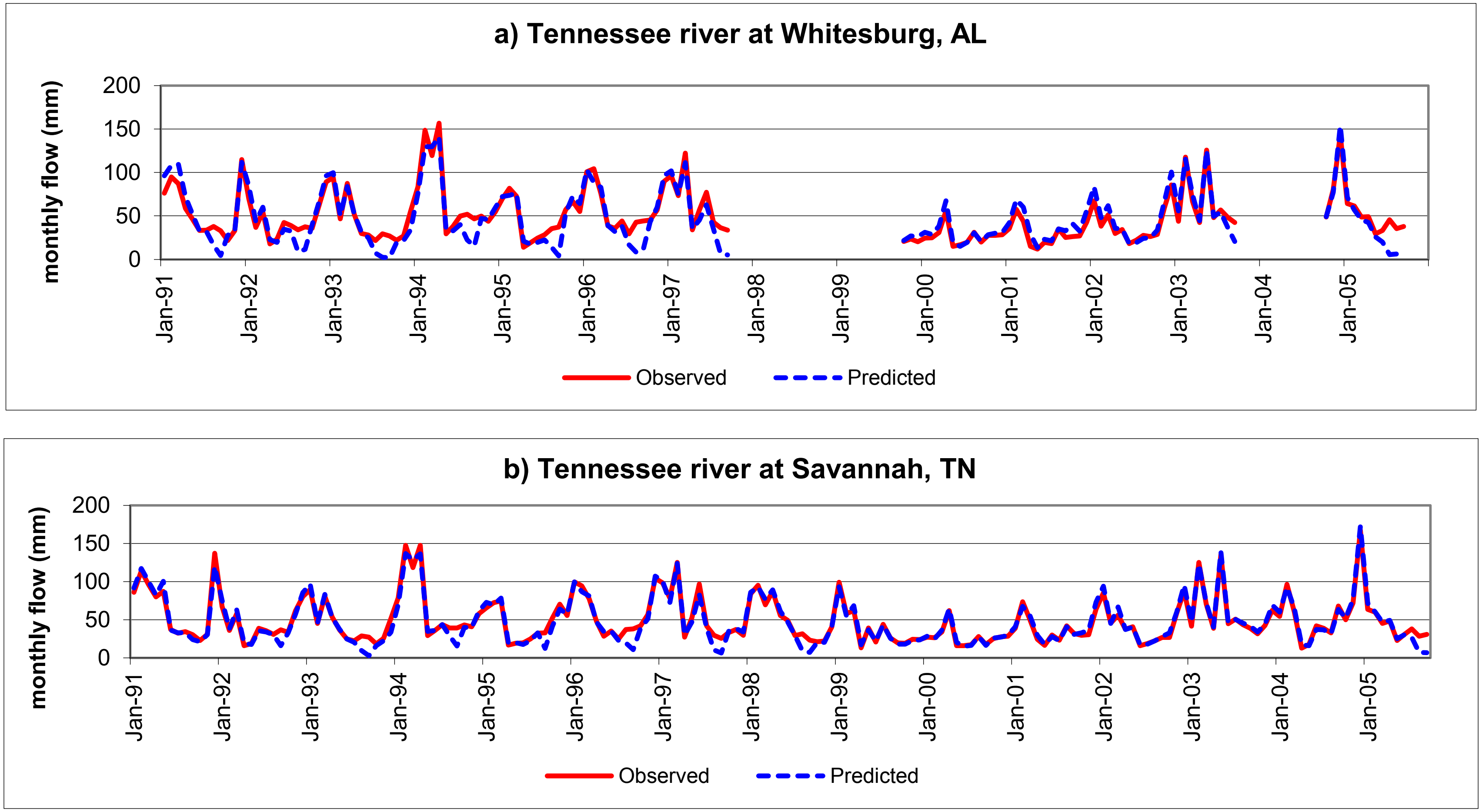


Figure 4-7 Average monthly stream flow for the Tennessee River basin-Validation period

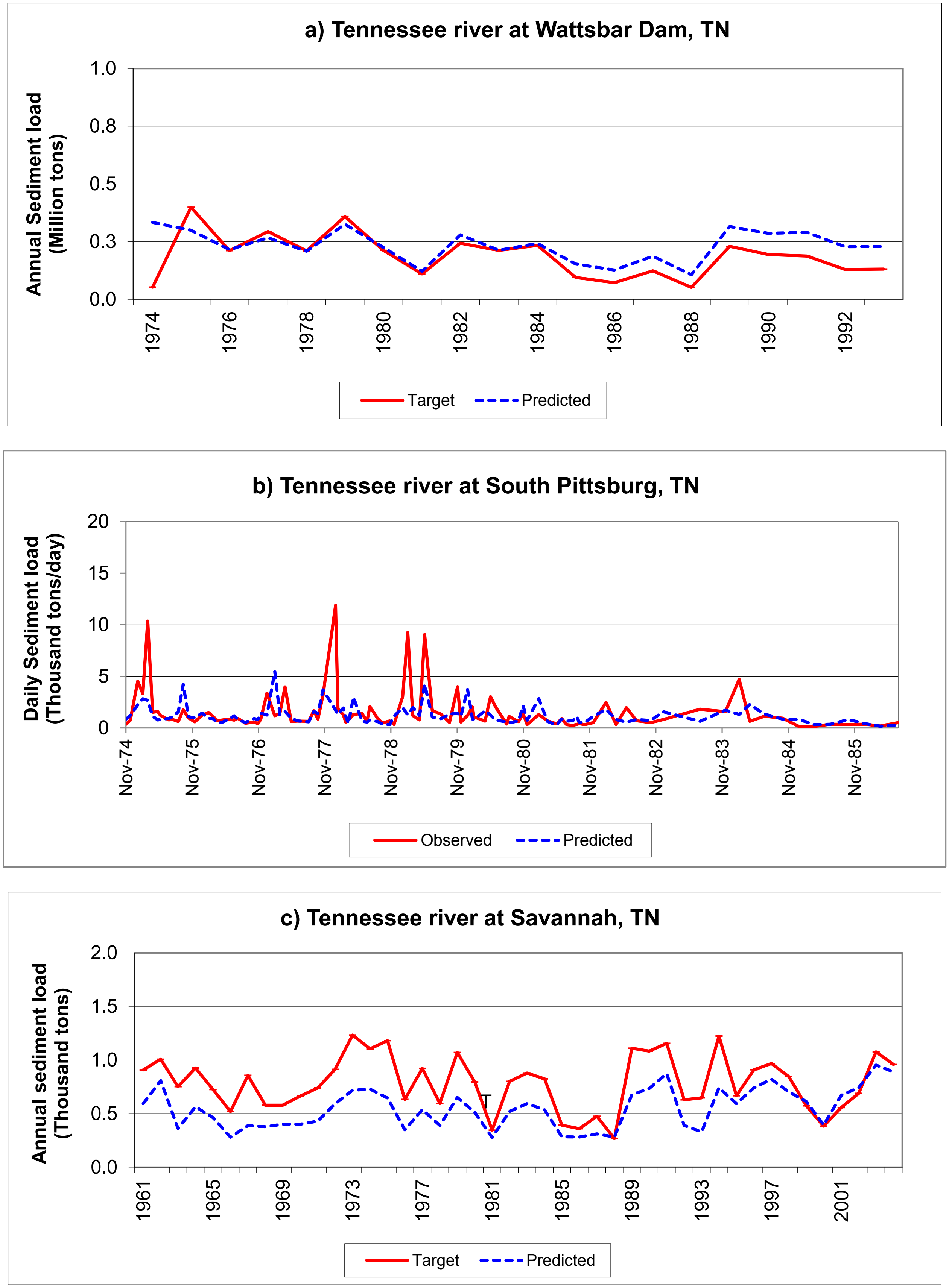


Figure 4-8 Average annual/daily sediment load for Tennessee River basin

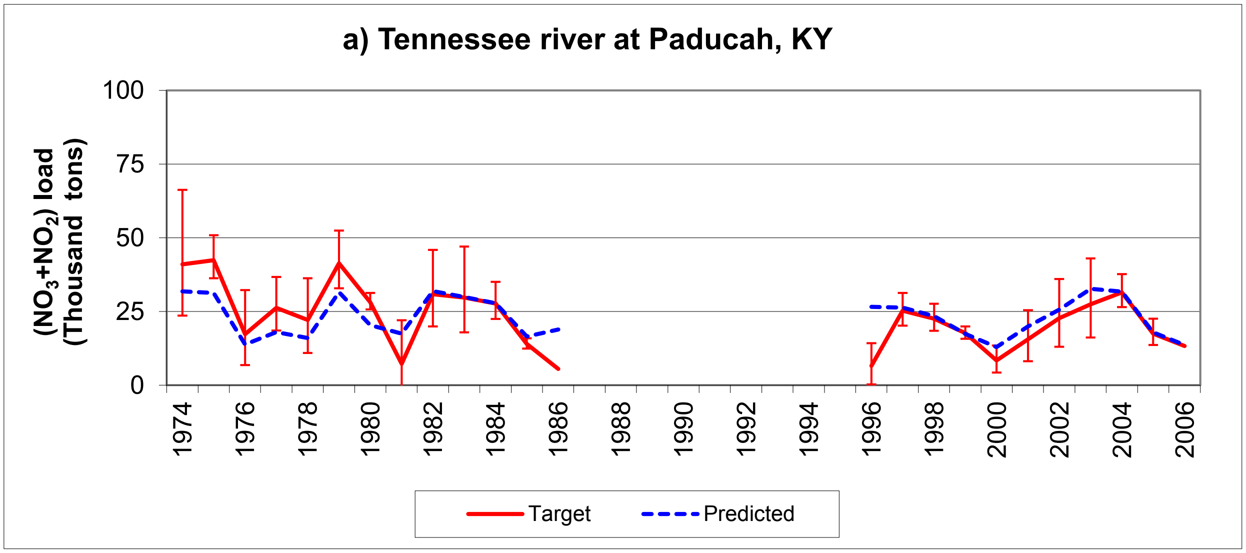


Figure 4-9 Average annual nitrite and nitrate Nitrogen (NO_2+NO_3) load for the Tennessee River basin

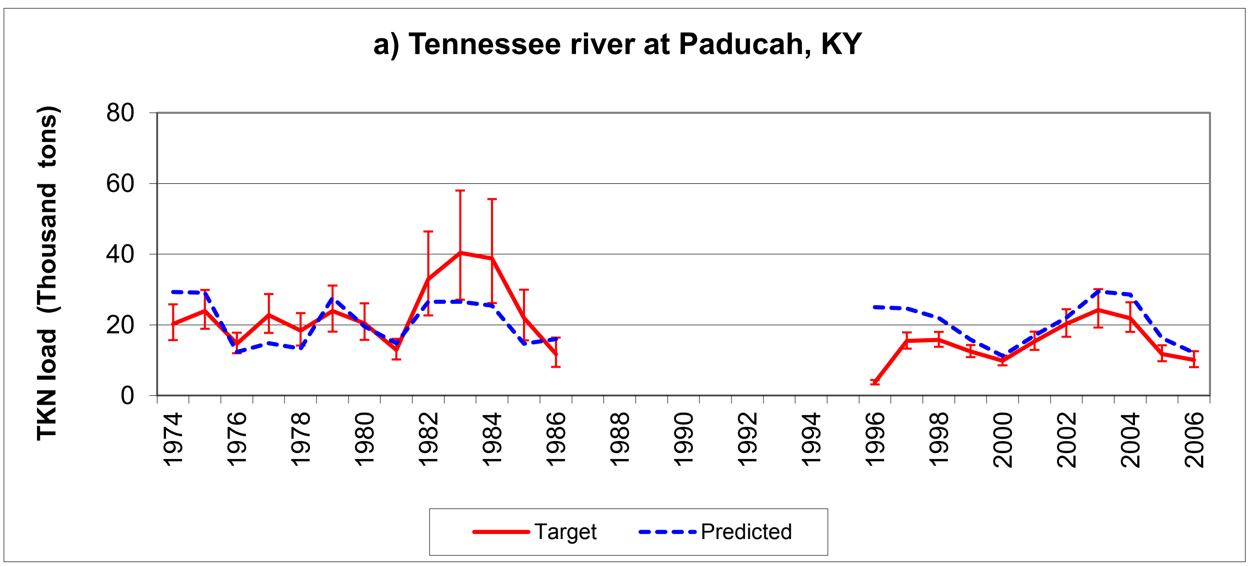


Figure 4-10 Average annual total Kjeldahl Nitrogen (TKN) load for the Tennessee River basin

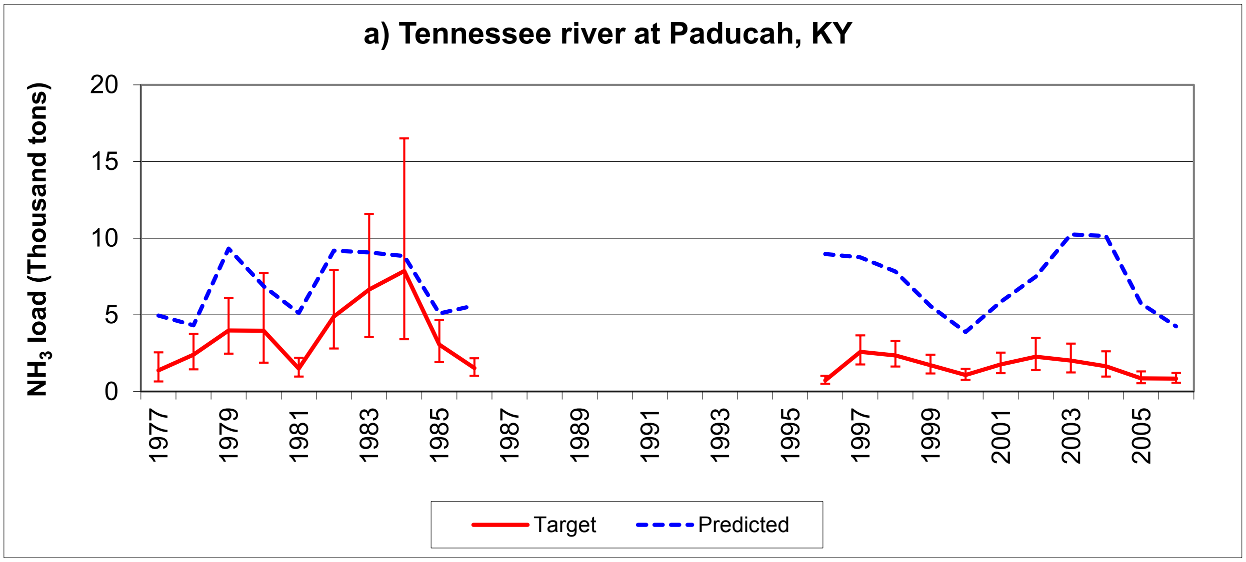


Figure 4-11 Average annual ammonia Nitrogen (NH_3) load for the Tennessee River basin

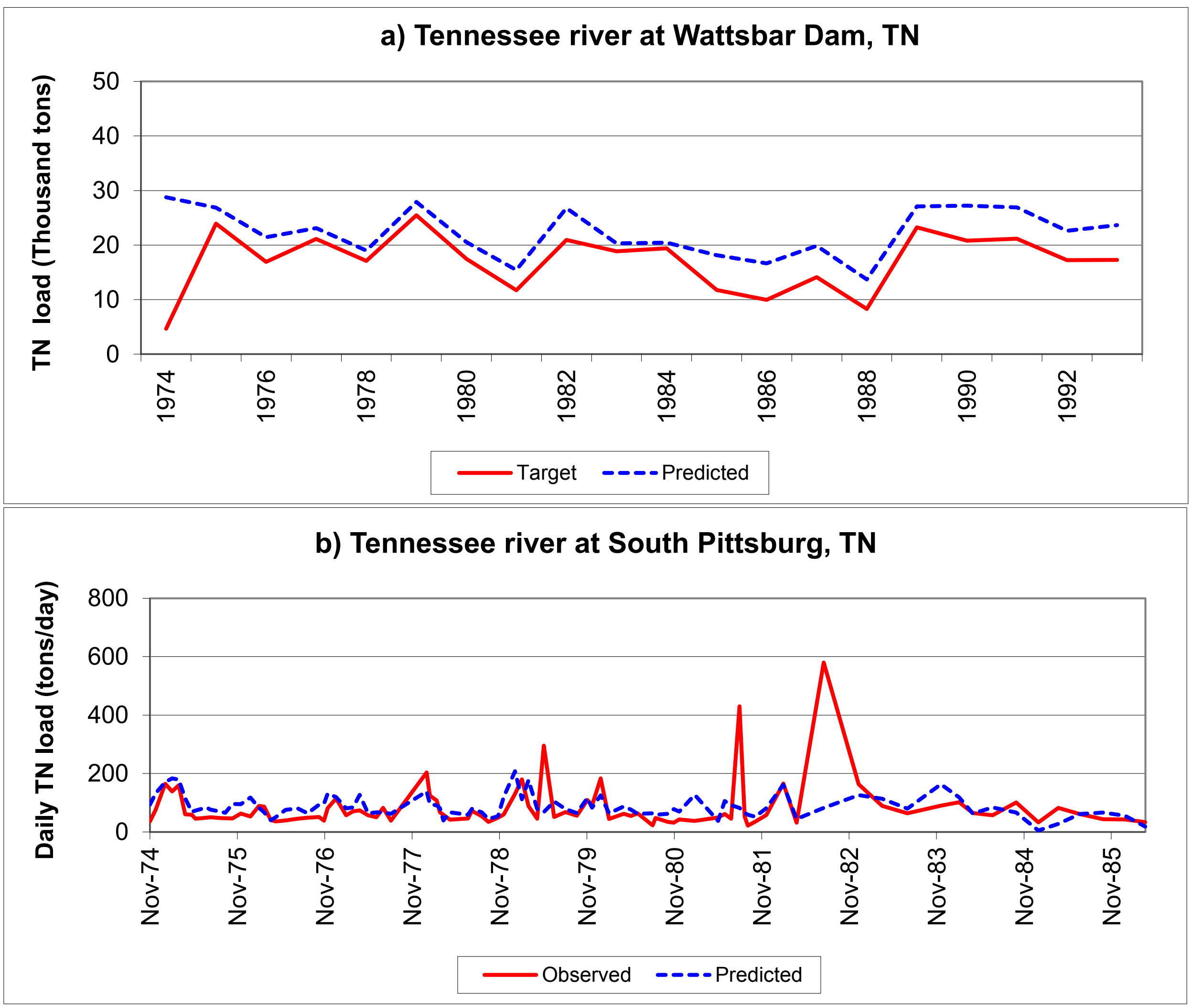


Figure 4-12 Average annual/daily total Nitrogen (TN) load for the Tennessee River basin

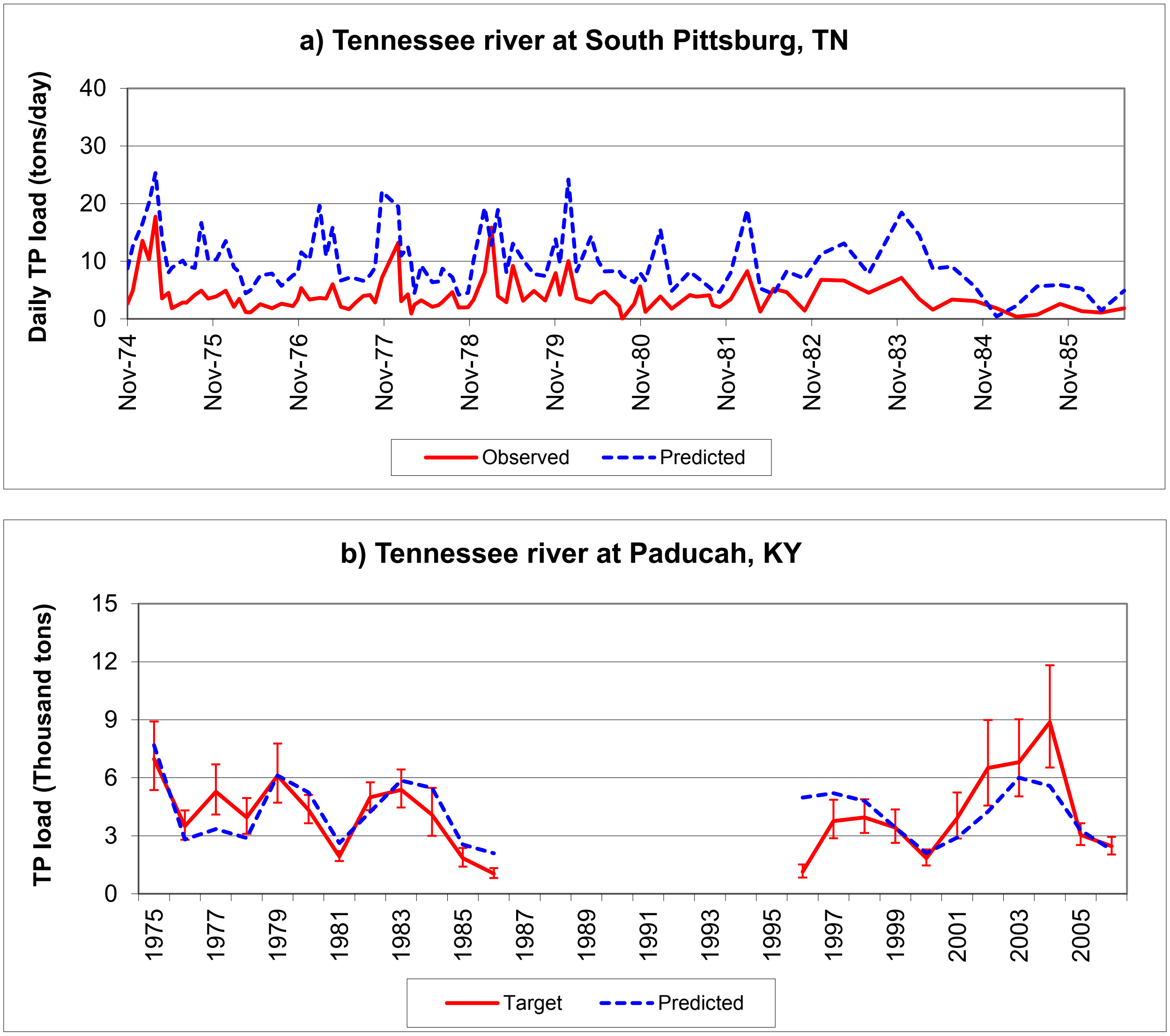


Figure 4-13 Average annual total Phosphorus (TP) load for the Tennessee River basin

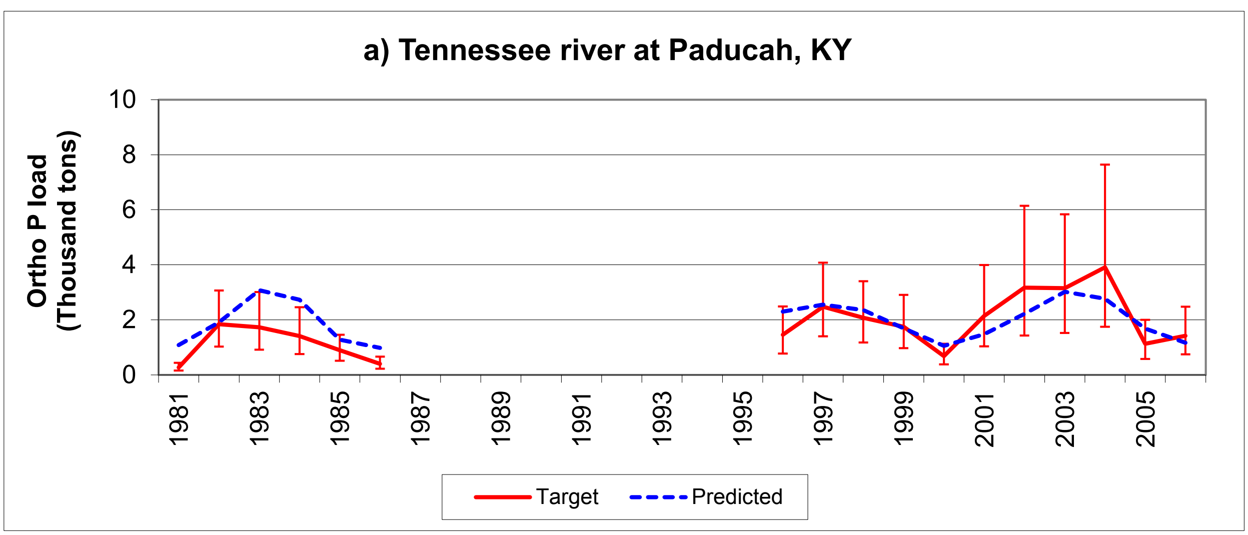


Figure 4-14 Average annual Ortho Phosphate (Ortho P) load for the Upper Mississippi river basin

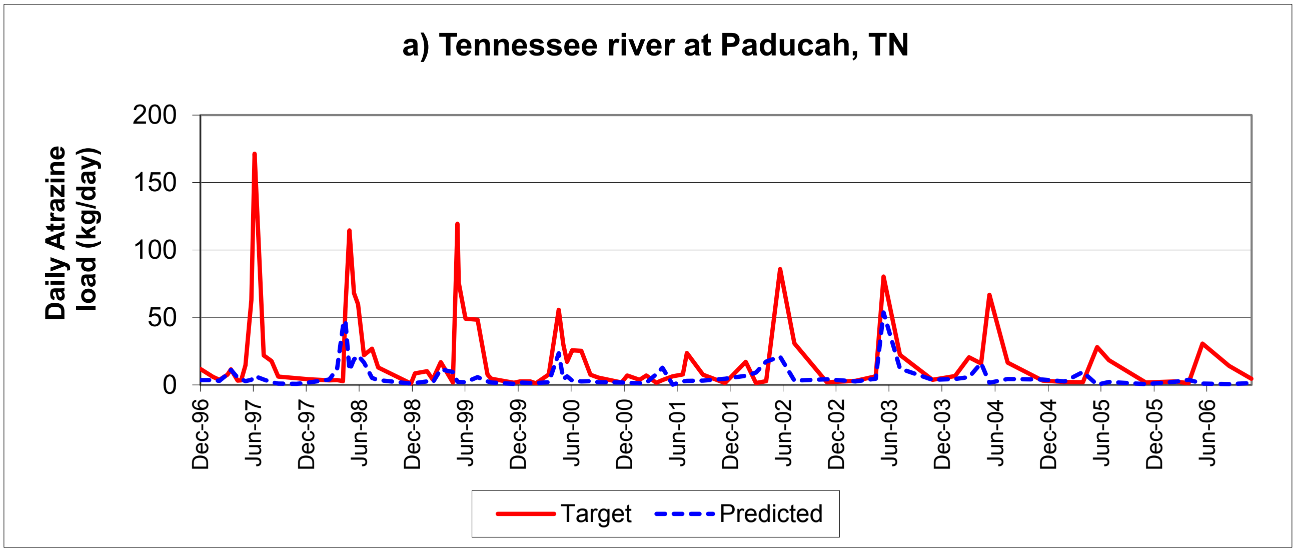


Figure 4-15 Average annual soluble Atrazine load for the Tennessee River basin

Table 4-6 Average annual Suspended Sediment load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Tennessee river at Wattsbar Dam, TN	06010201	232,660	187,588
Tennessee river at South Pittsburgh, TN*	06030001*	1,234*	1,525*
Tennessee river at Savannah, TN	06040001	544,689	1,039,571
Tennessee river near Paducah, KY*	06040006*	1,577*	2,865*

* Daily suspended sediment loads are estimated from grab samples. Annual loads are not available

Table 4-7a Average annual Nitrate and Nitrite Nitrogen load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Tennessee river near Paducah, KY	06040006	23,054	22,572

Table 4-7b Average annual total Kjeldahl Nitrogen load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Tennessee river near Paducah, KY	06040006	20,591	19,331

Table 4-7c Average annual Ammonia Nitrogen load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Tennessee river near Paducah, KY	06040006	7,006	2,625

Table 4-7d Average annual Total Nitrogen load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Tennessee river at Wattsbar Dam, TN	06010201	22,313	17,065
Tennessee river at South Pittsburgh, TN*	06030001	86.6*	81.4*
Tennessee river at Savannah, TN	06040001	42,306	43,557

* Daily total nitrogen loads are estimated from grab samples. Annual loads are not available

Table 4-8a Average annual Total Phosphorus load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Tennessee river at South Pittsburgh, TN*	06030001*	9.7*	4.1*
Tennessee river at Savannah, TN	06040001	5,098.7	4,319.0
Tennessee river near Paducah, KY	06040006	4,321	4,241

* Daily total phosphorus loads are estimated from grab samples. Annual loads are not available

Table 4-8b Average annual Ortho Phosphate load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Tennessee river near Paducah, KY	06040006	1,958	1,757

Table 4-9 Average daily Atrazine load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (kg/day)	Observed (kg/day)
Tennessee river near Paducah, KY	06040006	6.6	20.6

Chapter 5

Calibration and Validation of CEAP-HUMUS for the Ohio River Basin

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Chapter 5 describes results of calibration and validation of CEAP-HUMUS model setup for the Ohio River Basin. More details on procedures used in the calibration-validation process are presented in Chapter 1.

(Status: Complete)

This chapter addresses calibrations of APEX and HUMUS/SWAT for the Ohio River Basin (ORB) and to validate the CEAP modeling framework at selected gauging stations.

Calibration results of the average annual runoff at 8-digit watersheds

Average annual water yield from cultivated and non-cultivated land

The average annual simulated and targeted runoff of the 8-digit watersheds in the Ohio river basin is shown in Figure 5-2. Targeted and simulated runoff patterns concur with the precipitation patterns of this watershed. The regression relationship between targeted and simulated runoff at 8-digit watersheds (R^2 is 0.79), the means and standard deviations of annual runoff (of all the 8-digit watersheds in the basin) indicate that the model prediction is satisfactory (Figure 5-3 and Table 5-1). All the 8-digit watersheds except 11 were within the stipulated calibration goal of less than 20 % difference between predictions and target values of average annual water yield (Figure 5-3).

Annual and monthly flow calibration and validation at stream gages

Five USGS stream gages were selected in the ORB for annual and monthly flow calibration and validation (Figure 5-1). Calibration was performed for the period 1961 to 1990 to ensure that there was a reasonable agreement between predicted and observed flow at annual and monthly time steps. The model was validated for annual and monthly flows in the same stream gages for the period 1991 to 2006 without changing the calibrated input parameters.

Flow calibration and validation results at annual and monthly time step are shown in Figures 5-4 to 5-7 and Tables 5-2 to 5-5 for the stream gages located in Allegheny river (Natrona, PA), Ohio river (Sewickley, PA, Greenup, KY, and Metropolis, IL) and Kanawha river (Charleston, WV).

Observed and simulated flows at annual and monthly time steps matched very well for the calibration period (Figures 5-4 and 5-5). Means and standard deviations of predictions and observations are in close agreement (Table 5-2). In addition, the coefficient of determination is greater than 0.6 (R^2) and NSE is greater than 0.5 (table 5-3) for all the gauges (Except Sewickley, PA) during the calibration period. In summary, during calibration period, the model performance evaluation measures suggest an overall good agreement between observed and simulated flows at the annual and monthly time step, throughout the river basin.

Annual and monthly flow results for the above listed gauging stations for validation period are shown in (Figures 5-6 and 5-7 and tables 5-4 and 5-5). Based on R^2 and NSE it can be seen that all the gauges (except Charleston, WV) show acceptable predicted results from model. In summary, HUMUS-SWAT is able to capture the annual and monthly flow patterns very well in the Ohio river basin.

Sediment calibration

Predicted sediment results were validated in 4 different gauging stations (Figure 5-1) in ORB as outlined in Table 5-6. To limit the contents of this section, detailed results are shown only for three locations. However, the means are shown for all stations (Table 5-6). Figure 5-8 shows a detailed comparison of predicted and target sediment loads in Allegheny river at New Kensington, PA, Ohio river at Sewickley, PA, Greenup, KY and Metropolis, IL (Table 5-6, Figure 5-8) of annual sediment loads. For all the gauging stations analyzed, there is reasonable agreement between predictions and target values of sediment load (Figure 5-8). There is under-estimation of sediment in Greenup, KY and Metropolis, IL, which can be attributed to under-estimation of flow. However, the over-estimation in Natrona, PA and Sewickley, PA can possibly come from low modeled sediment deposition in the reaches and reservoirs. However, considering the quality of predicted sediment loads in all the places of validation, we could say the model results are good enough for making scenario trials.

Nutrient Calibration

Predicted nutrient results were validated in four gauging stations (Figure 5-1) in ORB as outlined in Tables 5-7, and Table 5-8. Detailed results are shown for only 3 gauges. However, the predicted and target means are shown for all the stations (Table 5-7 and Table 5-8). Figures 5-9 through 5-12 show a detailed comparison of predicted and target nutrient loads (various constituents of N and P) in Allegheny river at New Kensington, PA, Kanawha river at Winfield, WV, Ohio river at Greenup, KY and Metropolis, IL. Error bars or the upper and lower confidence levels of target values are also presented where available. In general, the predicted nitrogen loads (nitrate, nitrite, ammonia and organic) from HUMUS-SWAT are in good agreement with the target values. However, the individual forms are under or over estimated. Most of the over-estimation of nitrogen comes from the over-estimation of organic nitrogen (and also TKN). This is a result of over-estimation of sediment. The under-estimation of nitrogen mostly comes from under-estimation of soluble (NO_2+NO_3) form of nitrogen. This probably results from under-estimation of flow. With the exception of Allegheny River at New Kensington, PA all the gauges show acceptable model performance for Phosphorus and the modeled results were within the uncertainty limits of observations. The modeled total phosphorus result for Allegheny River at New Kensington, PA is over-estimated. However it was close to the upper uncertainty limit. The possible reason could be over-estimation of sediment load at this gauge.

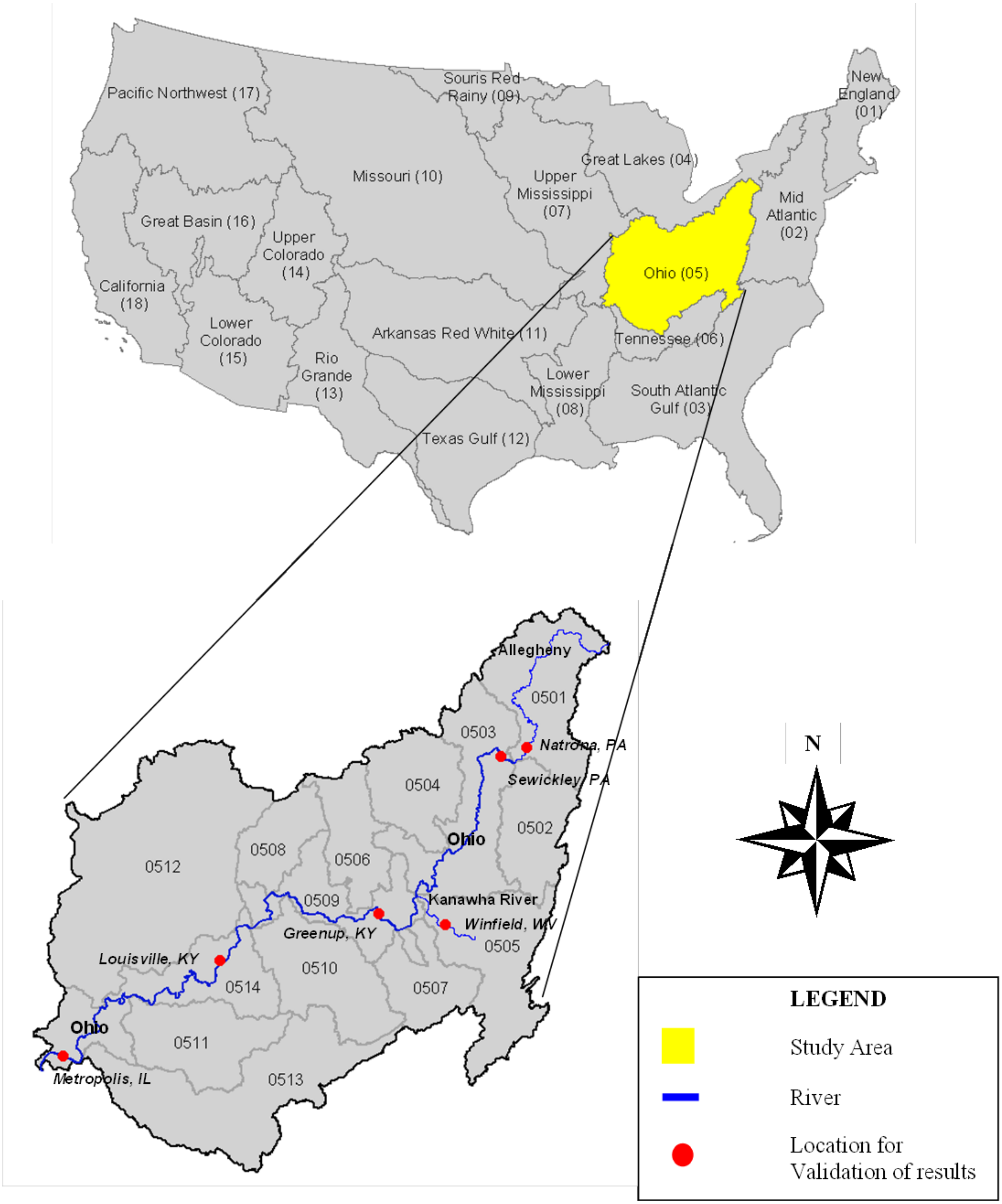
Atrazine calibration

For this river basin, the availability of atrazine observations was limited to one gauge only. Therefore, predicted atrazine results were validated in that gauge as outlined in Table 5-9, and Fig. 5-14. Figure 5-14 shows a detailed comparison of predicted and target atrazine loads in Ohio river at Metropolis, IL. In general, the pattern/trend and magnitude of predicted atrazine loads from

HUMUS-SWAT are in good agreement with the target values. However, the predicted atrazine loads are under-estimated. The under-estimation can be attributed to uncertainties in observations, procedure used to obtain annual loads from daily grab samples.

Table 5-1 Basin-average statistics for predicted and target annual water yield for all 8-digit watersheds in the CB watershed — Combined water yield results from APEX and SWAT after calibration (1961–90)

Calibration	Statistic	Value
Predictions (After calibration)	Mean (mm)	447.3
	Standard deviation (mm)	86.7
Observations	Mean (mm)	450.0
	Standard deviation (mm)	114.0



Pacific Northwest (17)
Souris Red Rainy (09)
New England (01)
Great Lakes (04)
Missouri (10)
Upper Mississippi (07)
Mid Atlantic (02)
Great Basin (16)
Upper Colorado (14)
California (18)
Ohio (05)
Lower Colorado (15)
Arkansas Red White (11)
Tennessee (06)
Rio Grande (13)
Lower Mississippi (08)
South Atlantic Gulf (03)
Texas Gulf (12)
Allegheny
0501
0503
Natrona, PA
Sewickley, PA
0504
0502
Ohio
0508
0506
0512
0509
Kanawha River
Winfield, WV
Greenup, KY
0505
Louisville, KY
0510
0514
0507
Ohio
0511
0513
Metropolis, IL
N
LEGEND
Study Area
River
Location for Validation of results

Figure 5-2 Average annual water yield of all 8-digit watersheds in the Ohio river basin from cultivated and non-cultivated area (combined water yield from APEX and SWAT)

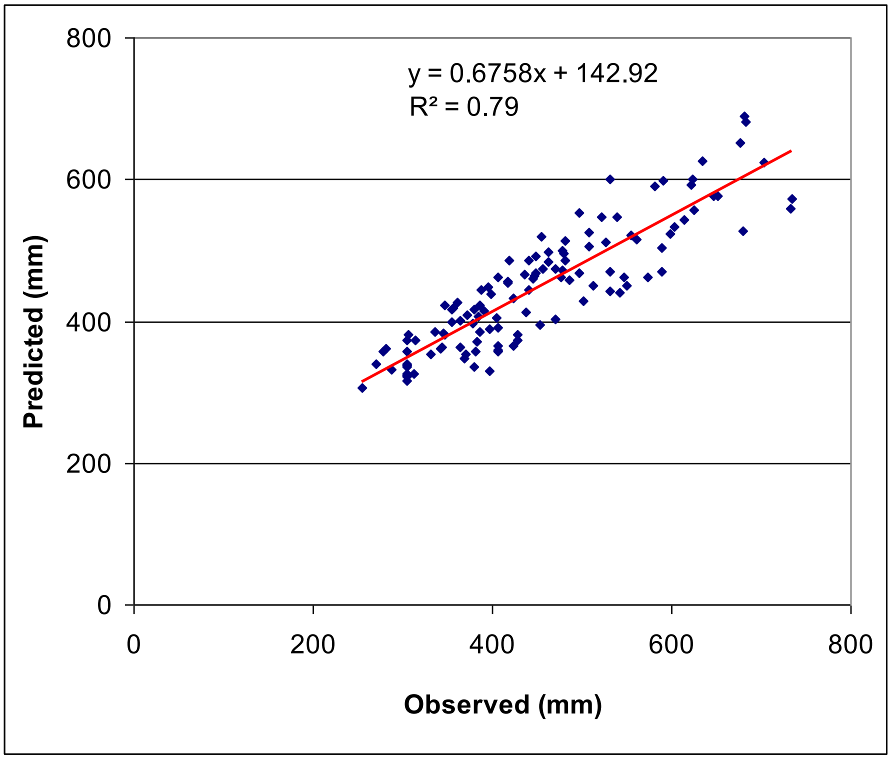


Figure 5-3 Percentage difference between predictions and observations of annual average flow in the ORB (combined water yield from APEX and SWAT after calibration

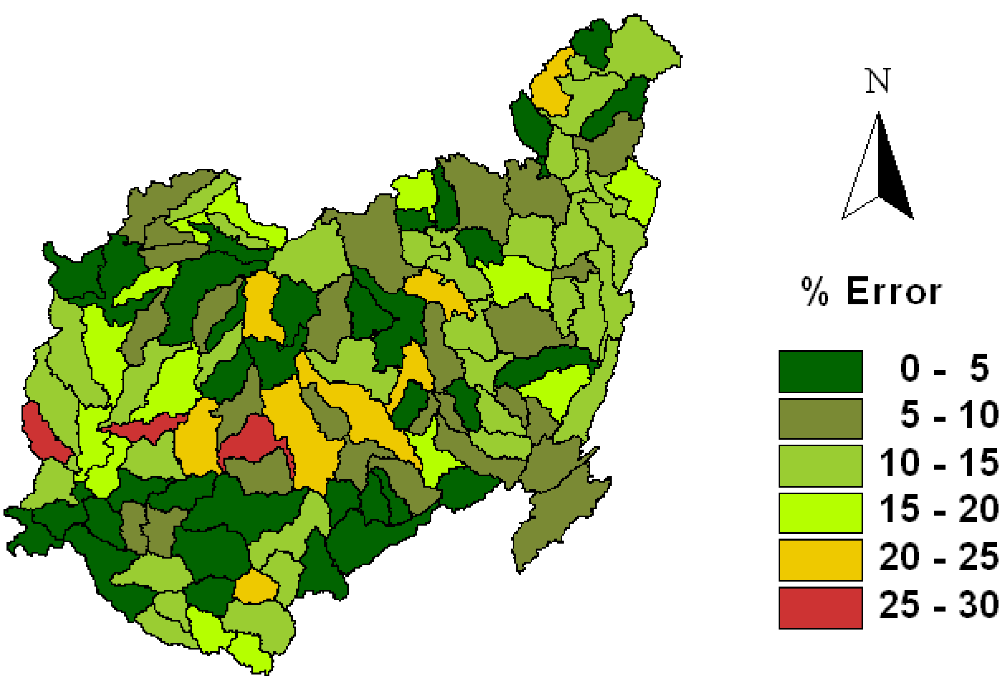
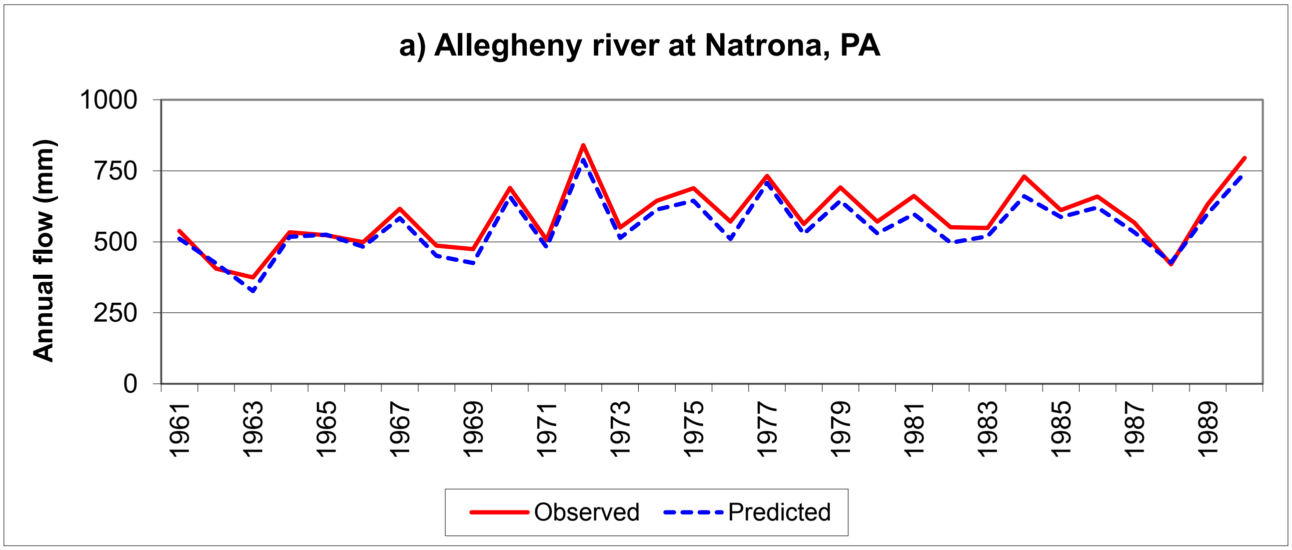
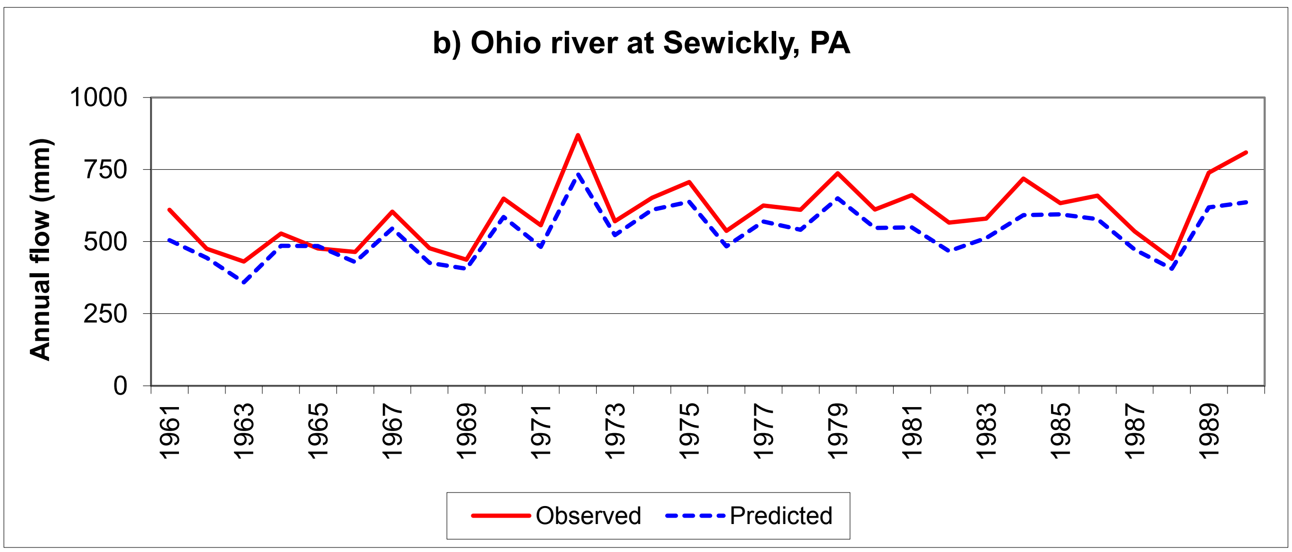


Figure 5-4 Average annual stream flow for the Ohio river basin-Calibration period





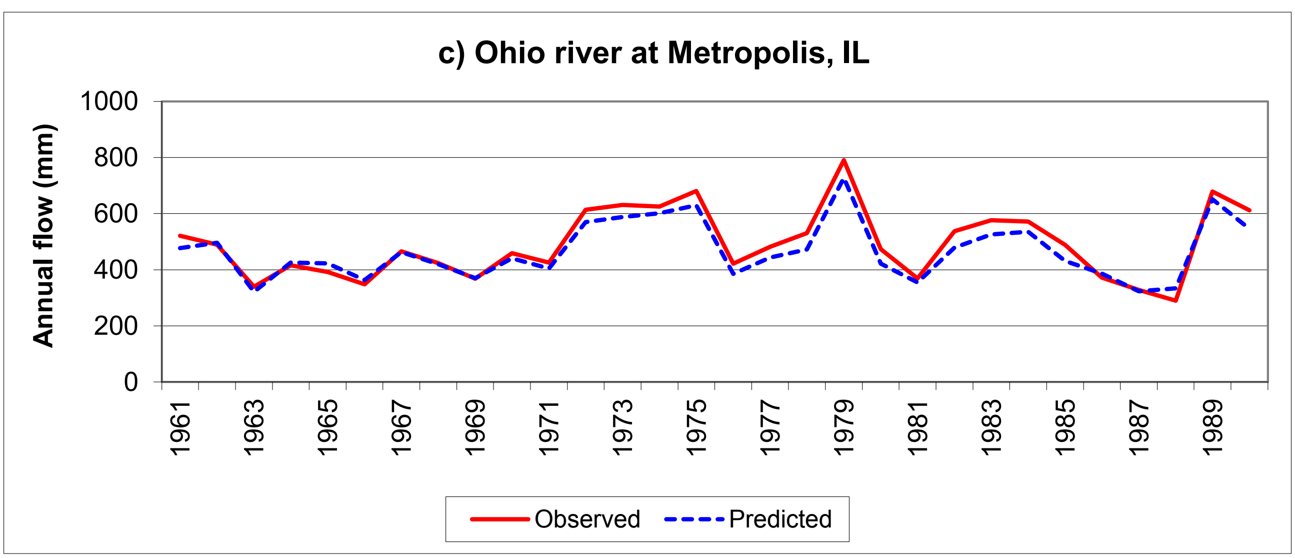


Figure 5-5 Average monthly stream flow for the Ohio river basin-Calibration period

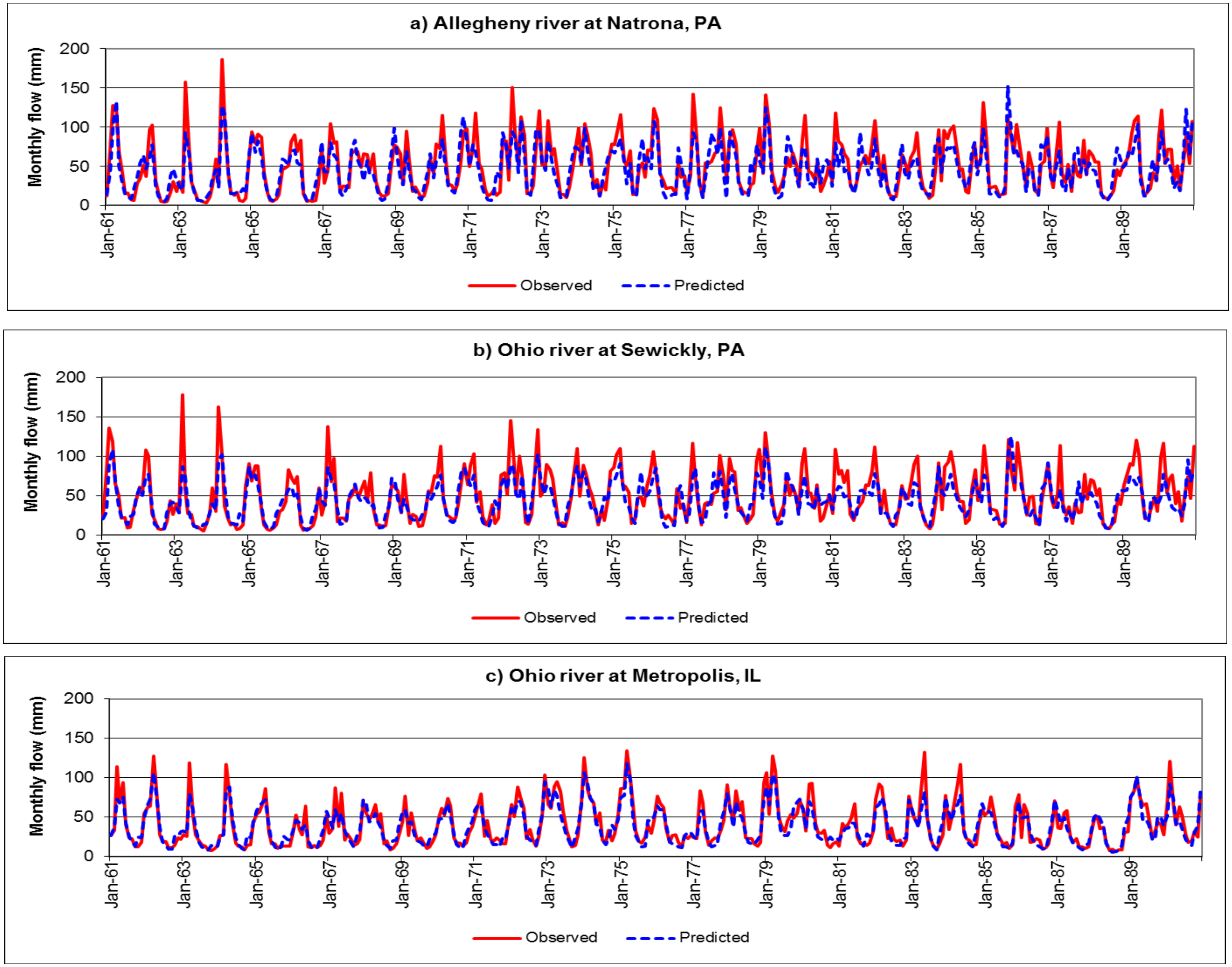
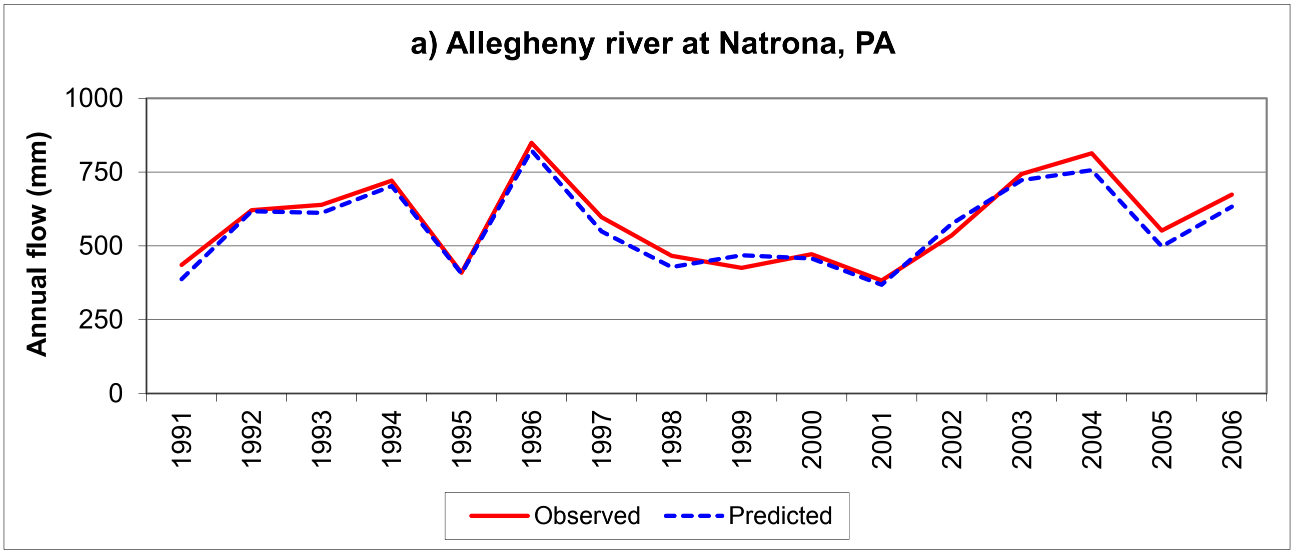
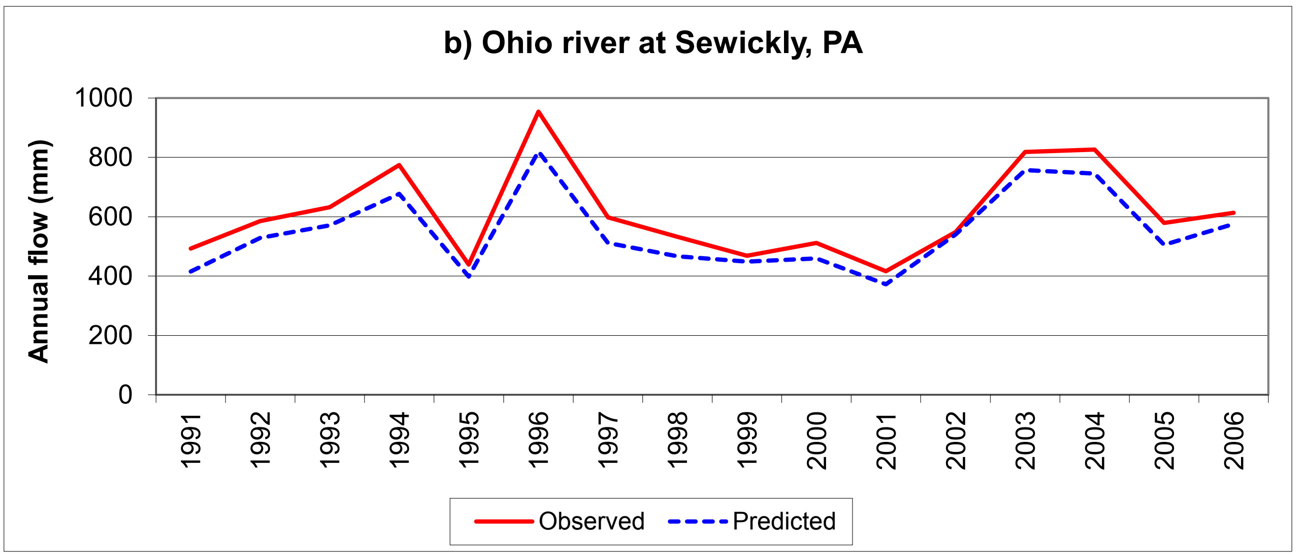


Figure 5-6 Average annual stream flow for the Ohio river basin-Validation period





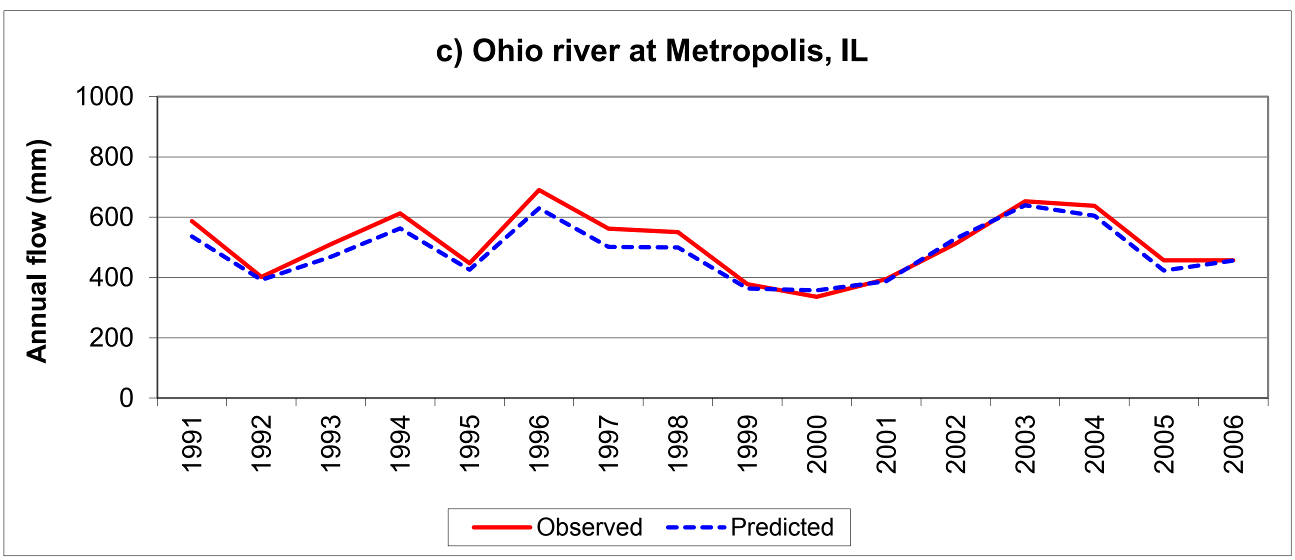


Figure 5-7 Average monthly stream flow for the Ohio river basin-Validation period

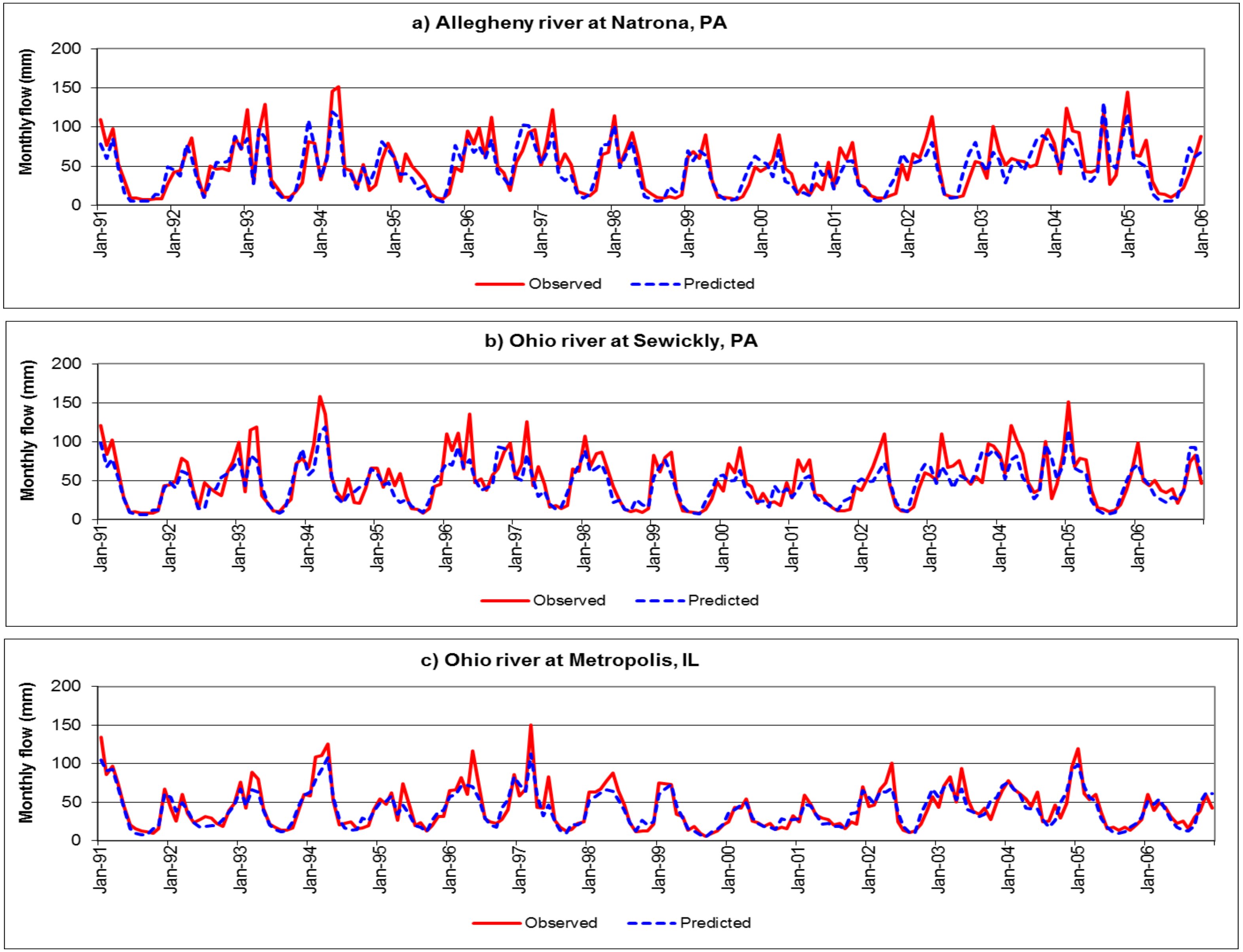


Table 5-2 Mean and standard deviation of the predicted and observed annual and monthly stream flow at selected gauging stations for the calibration period (1961-1990)

	Natrona, PA	Sewickley, PA	Charleston, WV	Greenup, KY	Metropolis, IL
Gauge details					
River	Allegheny river	Ohio river	Kanawha river	Ohio river	Ohio river
River reach-HUC	05010009	05030101	05050008	05090103	05140206
Drainage area (Km^2)	29,551.8	50,504.8	27,060.2	160,579.3	525,767.6
Data availability (period)	1961-1990	1961-1990	1961-1990	1969-1990	1961-1990
Mean flow (mm)					
Annual-Predictions	555.0	528.9	478.6	467.7	466.9
Annual-Observations	589.1	598.9	436.4	504.5	490.6
Monthly-Predictions	46.2	44.1	39.9	37.6	38.9
Monthly-Observations	50.3	49.9	42.6	41.8	40.9
Standard deviation (mm)					
Annual-Predictions	102.2	86.1	105.2	86.2	102.9
Annual-Observations	110.8	110.9	95.3	105.2	122.1
Monthly-Predictions	28.8	23.9	24.0	20.4	23.3
Monthly-Observations	33.9	32.9	29.4	27.4	28.1

Table 5-3 Coefficient of determination and efficiency of the predicted and observed annual and monthly stream flow at selected gauging stations for the calibration period (1961-1990)

	Natrona, PA	Sewickley, PA	Charleston, WV	Greenup, KY	Metropolis, IL
Gauge details					
River	Allegheny river	Ohio river	Kanawha river	Ohio river	Ohio river
River reach-HUC	05010009	05030101	05050008	05090103	05140206
Drainage area (Km^2)	29,551.8	50,504.8	27,060.2	160,579.3	525,767.6
Data availability (period)	1961-1990	1961-1990	1961-1990	1969-1990	1961-1990
R^2					
Annual	0.97	0.92	0.91	0.93	0.96
Monthly	0.76	0.76	0.57	0.71	0.87
Nash and Sutcliffe Efficiency					
Annual	0.87	0.47	0.69	0.78	0.90
Monthly	0.75	0.68	0.55	0.68	0.85

Table 5-4 Mean and standard deviation of the predicted and observed annual and monthly stream flow at selected gauging stations for the validation period (1991-2006)

	Natrona, PA	Sewickley, PA	Charleston, WV	Greenup, KY	Metropolis, IL
Gauge details					
River	Allegheny river	Ohio river	Kanawha river	Ohio river	Ohio river
River reach-HUC	05010009	05030101	05050008	05090103	05140206
Drainage area (Km^2)	29,551.8	50,504.8	27,060.2	160,579.3	525,767.6
Data availability (period)	1991-2006	1991-2006	1991-2002	2003-2006	1991-2006
Mean flow (mm)					
Annual-Predictions	562.8	549.6	486.4	568.1	486.2
Annual-Observations	583.6	611.9	423.5	598.1	511.6
Monthly-Predictions	46.9	45.8	42.8	40.0	40.5
Monthly-Observations	49.8	51.0	43.8	48.4	42.6
Standard deviation (mm)					
Annual-Predictions	140.7	135.1	106.9	130.0	92.3
Annual-Observations	147.9	154.4	97.9	132.0	107.2
Monthly-Predictions	28.9	25.4	26.0	22.3	23.0
Monthly-Observations	32.8	33.0	30.9	28.6	27.6

Table 5-5 Coefficient of determination and efficiency of the predicted and observed annual and monthly stream flow at selected gauging stations for the validation period (1991-2006)

	Natrona, PA	**Sewickley, PA**	**Charleston, WV**	**Greenup, KY**	**Metropolis, IL**
Gauge details					
River	Allegheny river	Ohio river	Kanawha river	Ohio river	Ohio river
River reach-HUC	05010009	05030101	05050008	05090103	05140206
Drainage area (Km^2)	29,551.8	50,504.8	27,060.2	160,579.3	525,767.6
Data availability (period)	1991-2006	1991-2006	1991-2002	2003-2006	1991-2006
R^2					
Annual	0.96	0.97	0.89	0.93	0.95
Monthly	0.77	0.77	0.58	0.74	0.86
Nash and Sutcliffe Efficiency					
Annual	0.94	0.79	0.41	0.86	0.88
Monthly	0.76	0.74	0.57	0.73	0.84

Figure 5-8 Average annual/daily sediment load for Ohio river basin

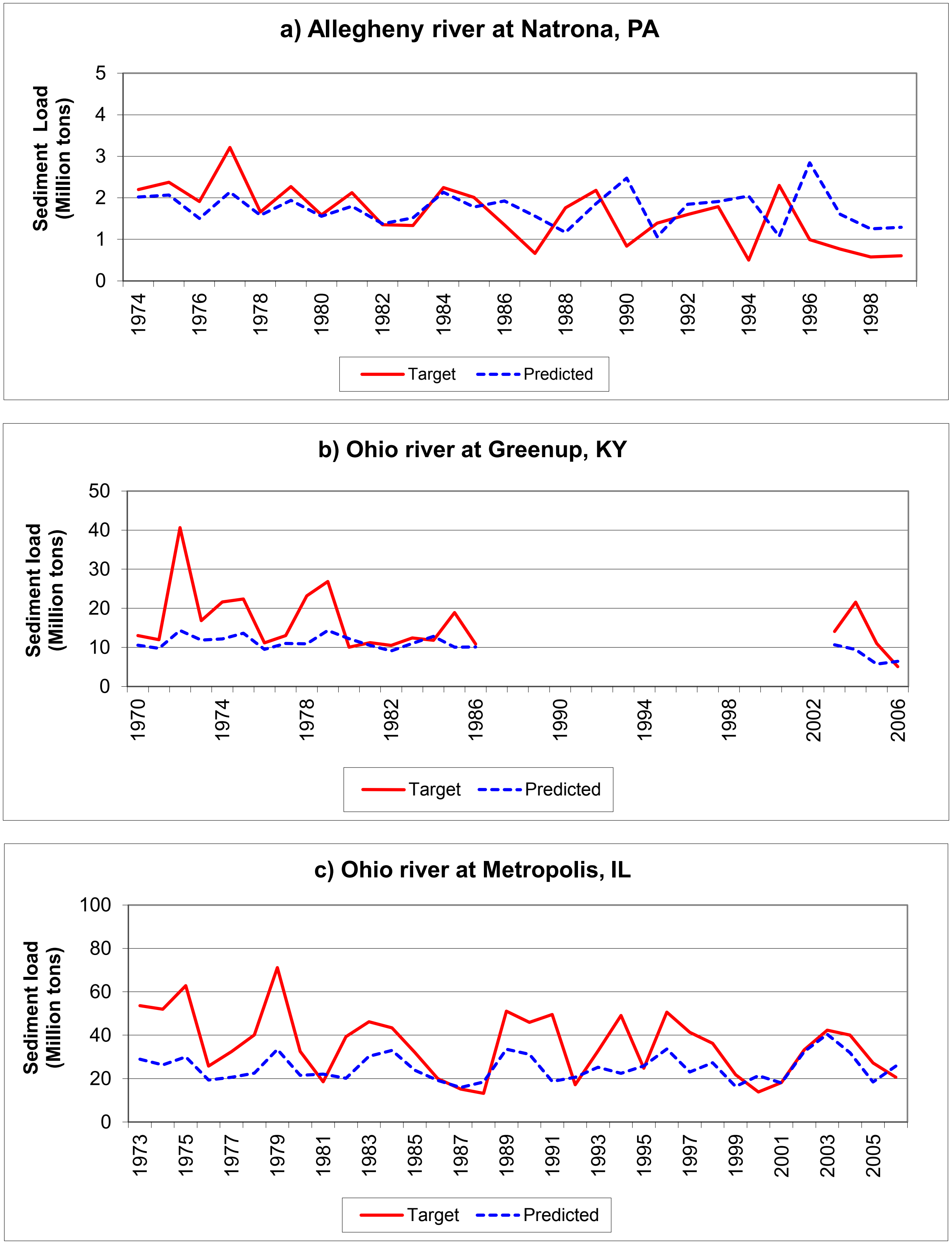


Figure 5-9 Average annual nitrite and nitrate Nitrogen (NO_2+NO_3) load for the Ohio river basin

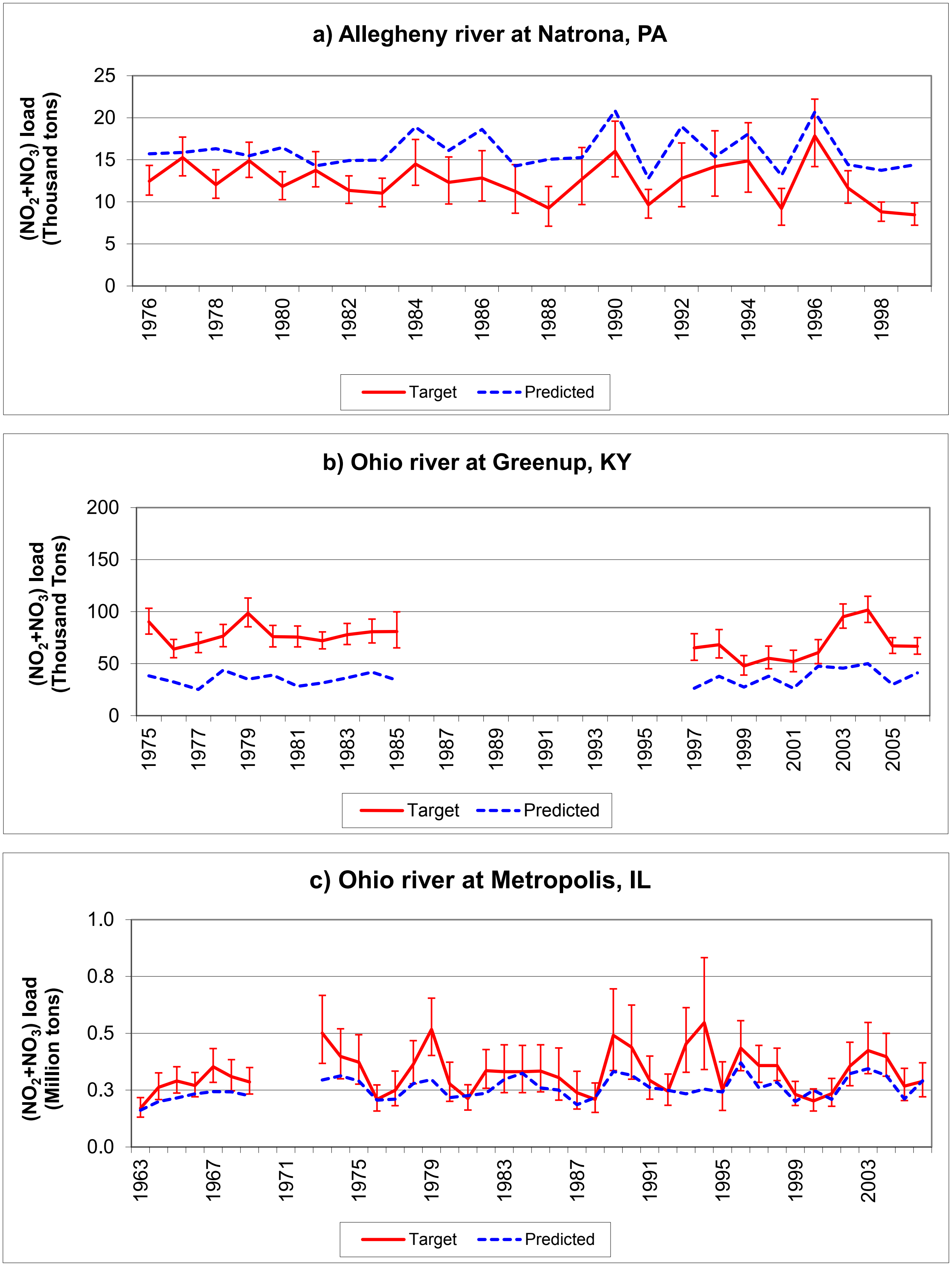


Figure 5-10 Average annual total Kjeldahl Nitrogen (TKN) load for the Ohio river basin

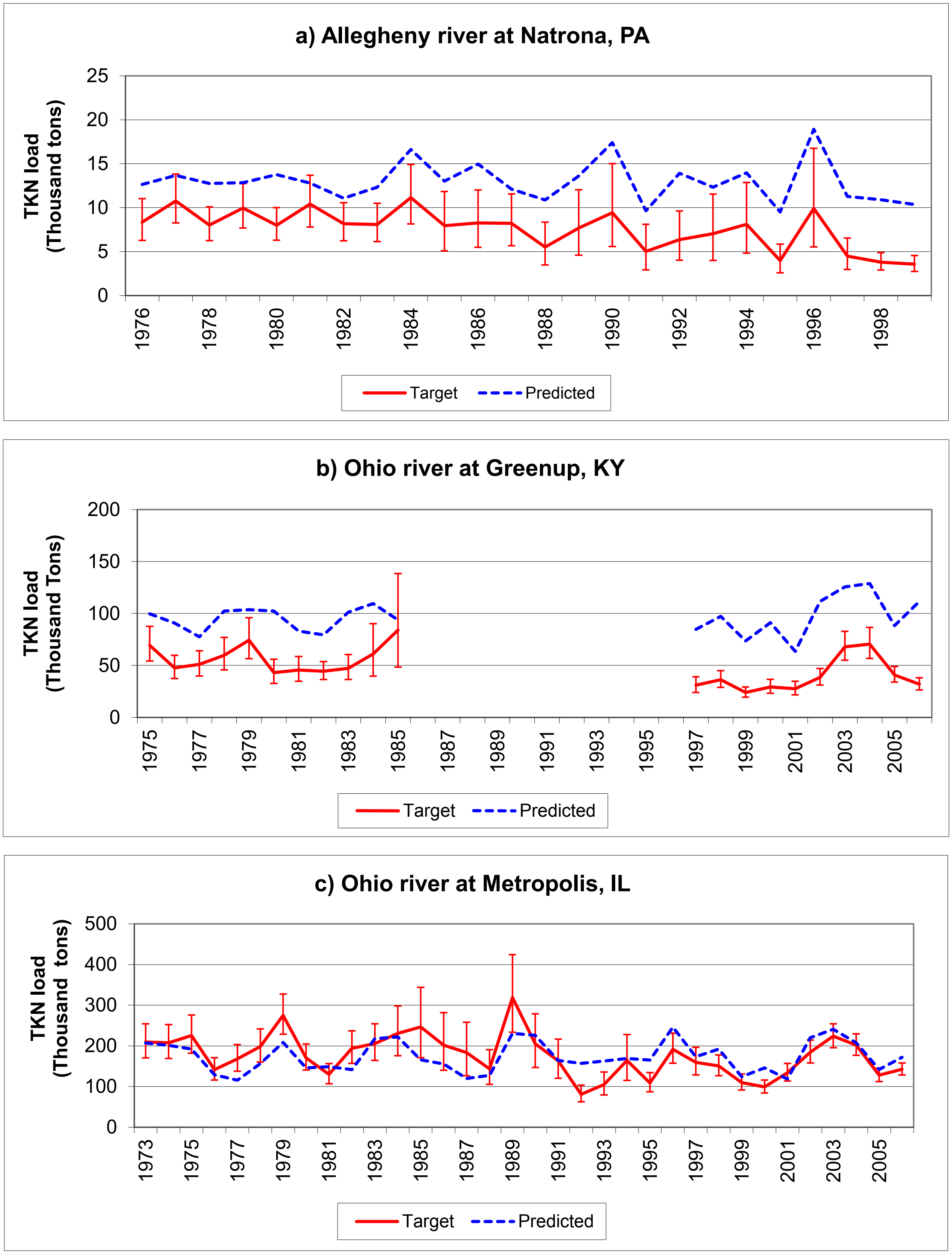


Figure 5-11 Average annual ammonia Nitrogen (NH_3) load for the Ohio river basin

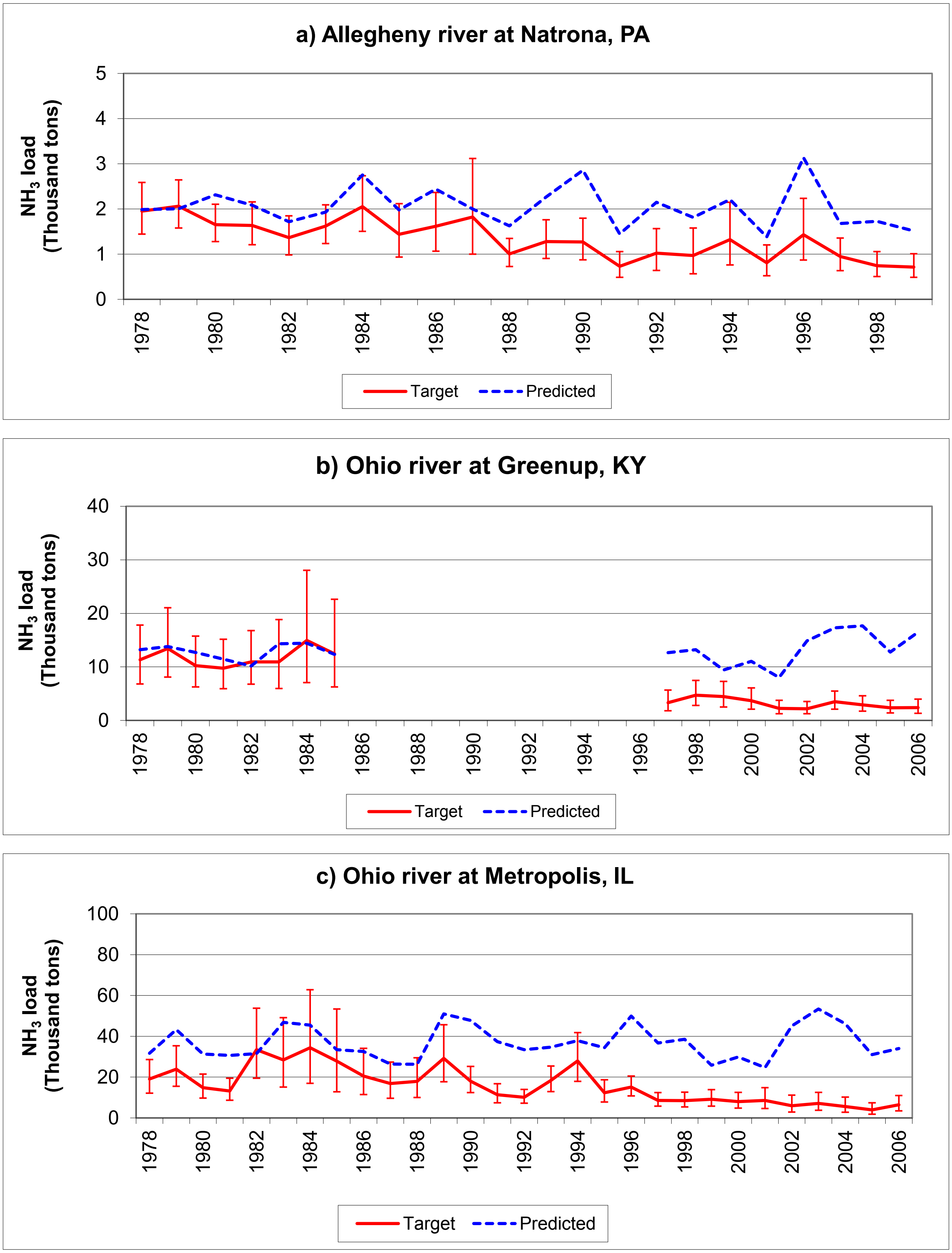
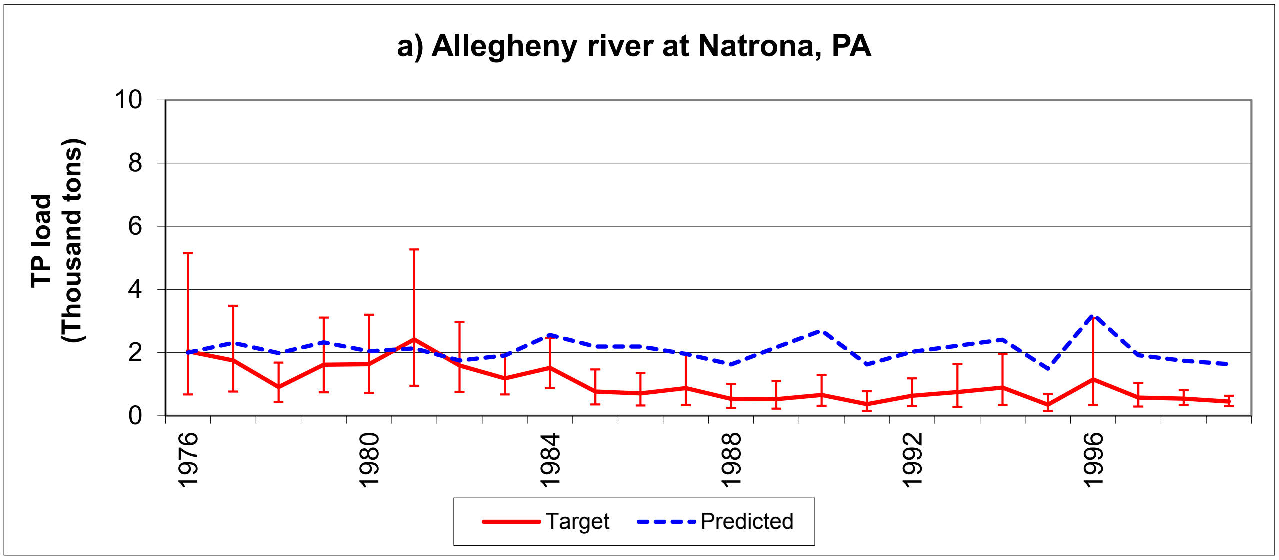
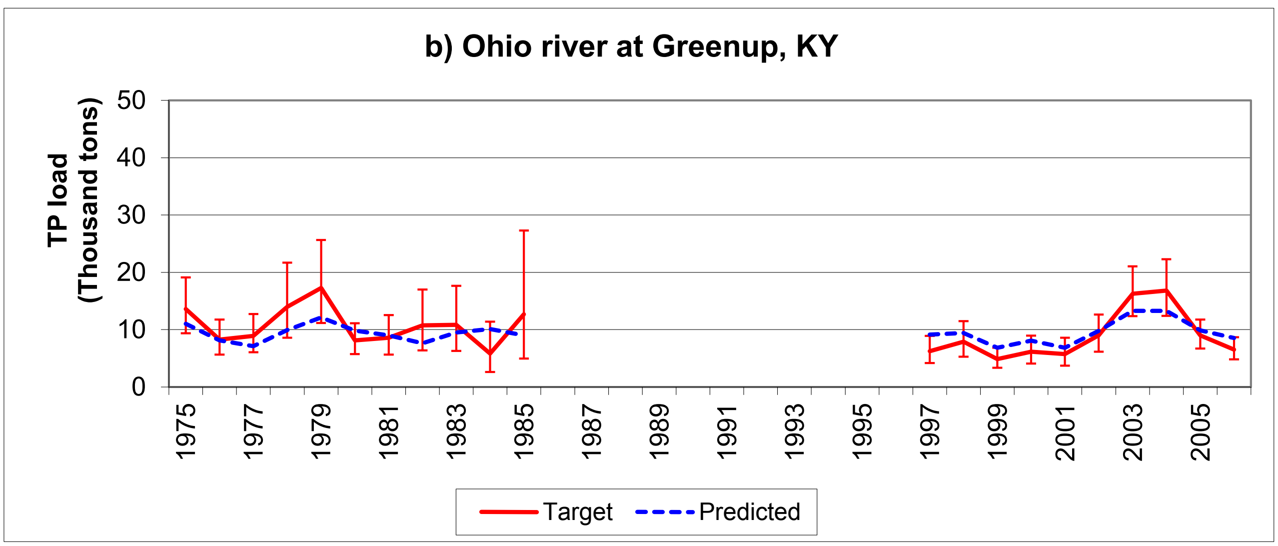


Figure 5-12 Average annual total Phosphorus (TP) load for the Ohio river basin





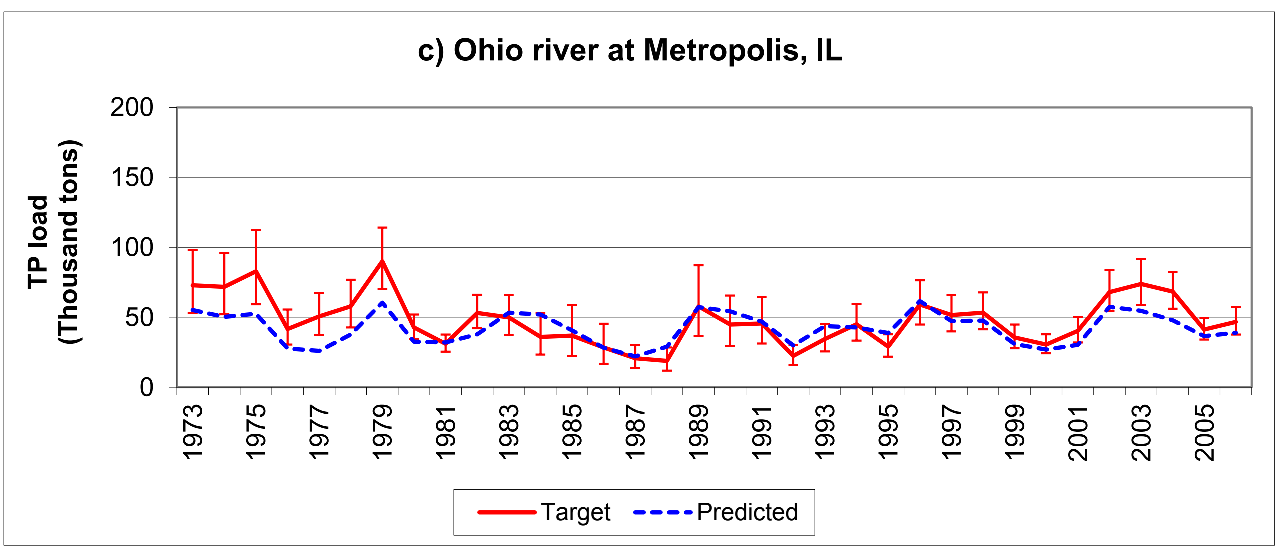


Figure 5-13 Average annual Ortho Phosphate (Ortho P) load for the Ohio river basin

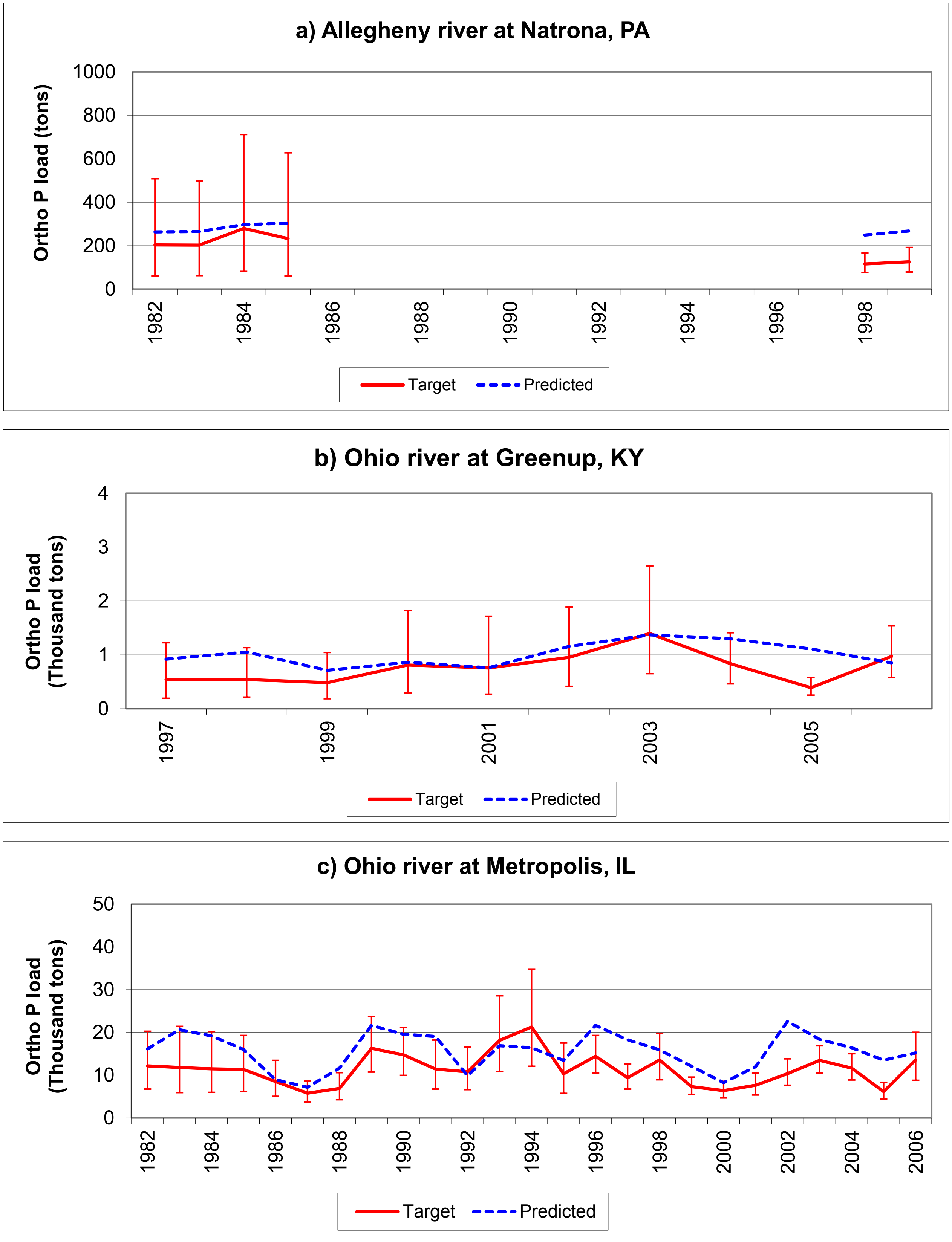


Figure 5-14 Average annual soluble Atrazine load for the Ohio river basin

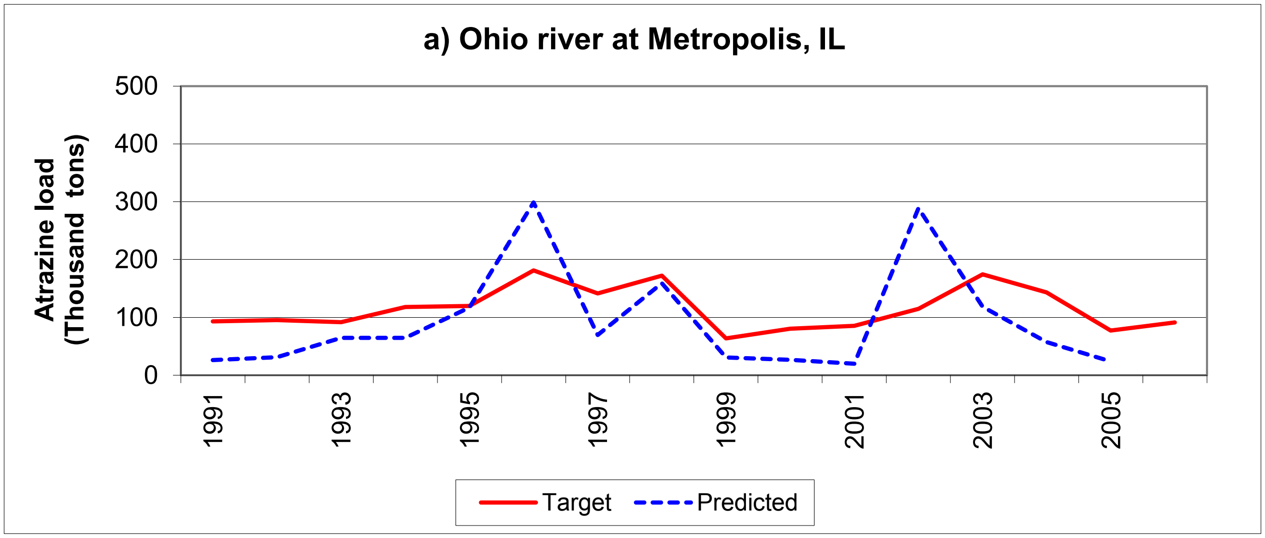


Table 5-6 Average annual Suspended Sediment load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Allegheny river at New Kensington, PA	05010009	1,742,038	1,598,451
Ohio river at Sewickley, PA	05030101	2,152,833	1,596,275
Ohio river near Greenup, KY	05090103	10,747,810	16,087,115
Ohio river at Metropolis, IL	05140206	25,027,353	35,681,209

Table 5-7a Average annual Nitrate and Nitrite Nitrogen load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Allegheny river at New Kensington, PA	05010009	16,020	12,451
Kanawha river at Winfield, WV	05050008	431	12,712
Ohio river near Greenup, KY	05090103	36,019	73,424
Ohio river at Metropolis, IL	05140206	257,540	326,568

Table 5-7b Average annual total Kjeldahl Nitrogen load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Allegheny river at New Kensington, PA	05010009	12,956	7,588
Kanawha river at Winfield, WV	05050008	14,813	10,237
Ohio river near Greenup, KY	05090103	96,159	48,825
Ohio river at Metropolis, IL	05140206	173,776	176,416

Table 5-7c Average annual Ammonia Nitrogen load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Allegheny river at New Kensington, PA	05010009	2,047	1,340
Kanawha river at Winfield, WV	05050008	2,519	1,321
Ohio river near Greenup, KY	05090103	13,110	6,993
Ohio river at Metropolis, IL	05140206	36,932	16,013

Table 5-8a Average annual Total Phosphorus load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Allegheny river at New Kensington, PA	05010009	2,084	1,014
Kanawha river at Winfield, WV	05050008	1,169	809
Ohio river near Greenup, KY	05090103	9,435	9,858
Ohio river at Metropolis, IL	05140206	41,398	48,000

Table 5-8b Average annual Ortho Phosphate load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Allegheny river at New Kensington, PA	05010009	274	193
Kanawha river at Winfield, WV	05050008	182	174
Ohio river near Greenup, KY	05090103	1,009	768
Ohio river at Metropolis, IL	05140206	15,624	11,388

Table 5-9 Average daily Atrazine load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Ohio river at Metropolis, IL	05140206	90.3	115.1

Chapter 6

Calibration and Validation of CEAP-HUMUS for the Great Lakes River Basin

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Chapter 6 describes results of calibration and validation of CEAP-HUMUS model setup for the Great Lakes River Basin. More details on procedures used in the calibration-validation process are presented in Chapter 1.

(Status: Complete)

This chapter addresses calibrations of APEX and HUMUS/SWAT for the Great Lakes River Basin (GLRB) and to validate the CEAP modeling framework at selected gauging stations.

Calibration results of the average annual runoff at 8-digit watersheds

Average annual water yield from cultivated and non-cultivated land

The average annual simulated and targeted runoff of the 8-digit watersheds in the Great Lakes river basin is shown in Figure 6-2. Targeted and simulated runoff patterns concur with the precipitation patterns of this watershed. The regression relationship between targeted and simulated runoff at 8-digit watersheds (R^2 is 0.84), the means and standard deviations of annual runoff (of all the 8-digit watersheds in the basin) indicate that the model prediction is satisfactory (Figure 6-3 and Table 6-1). All the 8-digit watersheds except 18 were within the stipulated calibration goal of less than 20 % difference between predictions and target values of average annual water yield (Figure 6-3).

Annual and monthly flow calibration and validation at stream gages

Four USGS stream gages were selected in the GLRB for annual and monthly flow calibration and validation (Figure 6-1). Calibration was performed for the period 1961 to 1990 to ensure that there was a reasonable agreement between predicted and observed flow at annual and monthly time steps. The model was validated for annual and monthly flows in the same stream gages for the period 1991 to 2006 without changing the calibrated input parameters.

Flow calibration and validation results at annual and monthly time step are shown in Figures 6-4 to 6-7 and Tables 6-2 to 6-5 for the stream gages located in St Louis river (Scanlon, MN), Grand river (Grand Rapids, MI), Maumee river (Waterville, OH) and Oswego river (Oswego, NY).

Observed and simulated flows at annual and monthly time steps matched very well for the calibration period (Figures 6-4 and 6-5). Means and standard deviations of predictions and observations are in close agreement (Table 6-2). In addition, the coefficient of determination is greater than 0.6 (R^2) and NSE is greater than 0.5 (table 6-3) for all the gauges (Except Scanlon, MN) during the calibration period. In summary, during calibration period, the model performance evaluation measures suggest an overall good agreement between observed and simulated flows at the annual and monthly time step, throughout the river basin.

Annual and monthly flow results for the above listed gauging stations for validation period are shown in (Figures 6-6 and 6-7 and tables 6-4 and 6-5). Based on R^2 and NSE it can be seen that all the gauges show acceptable predicted results from model. In summary, HUMUS-SWAT is able to capture the annual and monthly flow patterns very well in the Great Lakes river basin.

Sediment calibration

Predicted sediment results were validated in 5 different gauging stations (Figure 6-1) in GLRB as outlined in Table 6-6. To limit the contents of this section, detailed results are shown only for three locations. However, the means are shown for all stations (Table 6-6). Figure 6-8 shows a detailed comparison of predicted and target annual sediment loads in St Louis river at Scanlon, MN, Saginaw river at Saginaw, MI, and Maumee river at Waterville, OH (Table 6-6, Figure 6-8). For all the gauging stations analyzed, there is good agreement between predictions and target values of sediment load (Figure 6-8). There is under-estimation of sediment in Saginaw, MI and Independence, OH, which can be attributed to under-estimation of flow. However, the over-estimation in Scanlon, MN and Waterville, OH can possibly come from over estimation of flow and low deposition of sediment in reaches. However, considering the quality of predicted sediment loads in all the places of validation, we could say the model results are good enough for making scenario trials.

Nutrient Calibration

Predicted nutrient results were validated in five gauging stations (Figure 6-1) in GLRB as outlined in Tables 6-7, and Table 6-8. Detailed results are shown for only 3 gauges. However, the predicted and target means are shown for all the stations (Table 6-7 and Table 6-8). Figures 6-9 through 6-13 show a detailed comparison of predicted and target nutrient loads (various constituents of N and P) in St Louis river at Scanlon, MN, Saginaw river at Saginaw, MI, and Maumee river at Waterville, OH. Error bars or the upper and lower confidence levels of target values are also presented where available. In general, the predicted nutrient loads from HUMUS-SWAT are in good agreement with the target values and within the uncertainty limits of target values for most of the nutrient constituent-location combinations (except some at Scanlon, MN and Waterville, OH). The over-estimation of TKN at St Louis river at Scanlon, MN could be attributed to the over-estimation of sediment. The under-estimation of TKN in Maumee river at Waterville, OH can come from the over-estimation of NO_2+NO_3 form of nitrogen. With the exception of soluble phosphorus in Sanlon, MN and Waterville, OH all the gauges show acceptable model performance for Phosphorus and the modeled results were within the uncertainty limits of observations. The modeled orthophosphate result for St Louis river at Scanlon, MN and Maumee river at Waterville, OH not within the uncertainty of observations. The possible reason for the over estimation could be over-estimation of flow at this gauge. More details on water quality results for Fox river and Cuyahoga river were not described because they have poor data and drain a very small area.

Atrazine calibration

For this river basin, the availability of atrazine observations was limited to one gauge only. Therefore, predicted atrazine results were validated in that gauge as outlined in Table 6-9, and Fig. 6-14. Figure 6-14 shows a detailed comparison of predicted and target atrazine loads in Maumee river at Waterville, OH. In general, the pattern/trend and magnitude of predicted atrazine loads from HUMUS-SWAT are in good agreement with the target values. However, the predicted atrazine loads are under-estimated. The under-estimation can be attributed to uncertainties in observations, procedure used to obtain annual loads from daily grab samples.

Table 6-1 Basin-average statistics for predicted and target annual water yield for all 8-digit watersheds in the GL river basin — Combined water yield results from APEX and SWAT after calibration (1961–90)

Calibration	Statistic	Value
Predictions (After calibration)	Mean (mm) Standard deviation (mm)	317.3 124.5
Observations	Mean (mm) Standard deviation (mm)	338.7 149.6

Figure 6-1 Location of Great Lakes River Basin and sampling locations

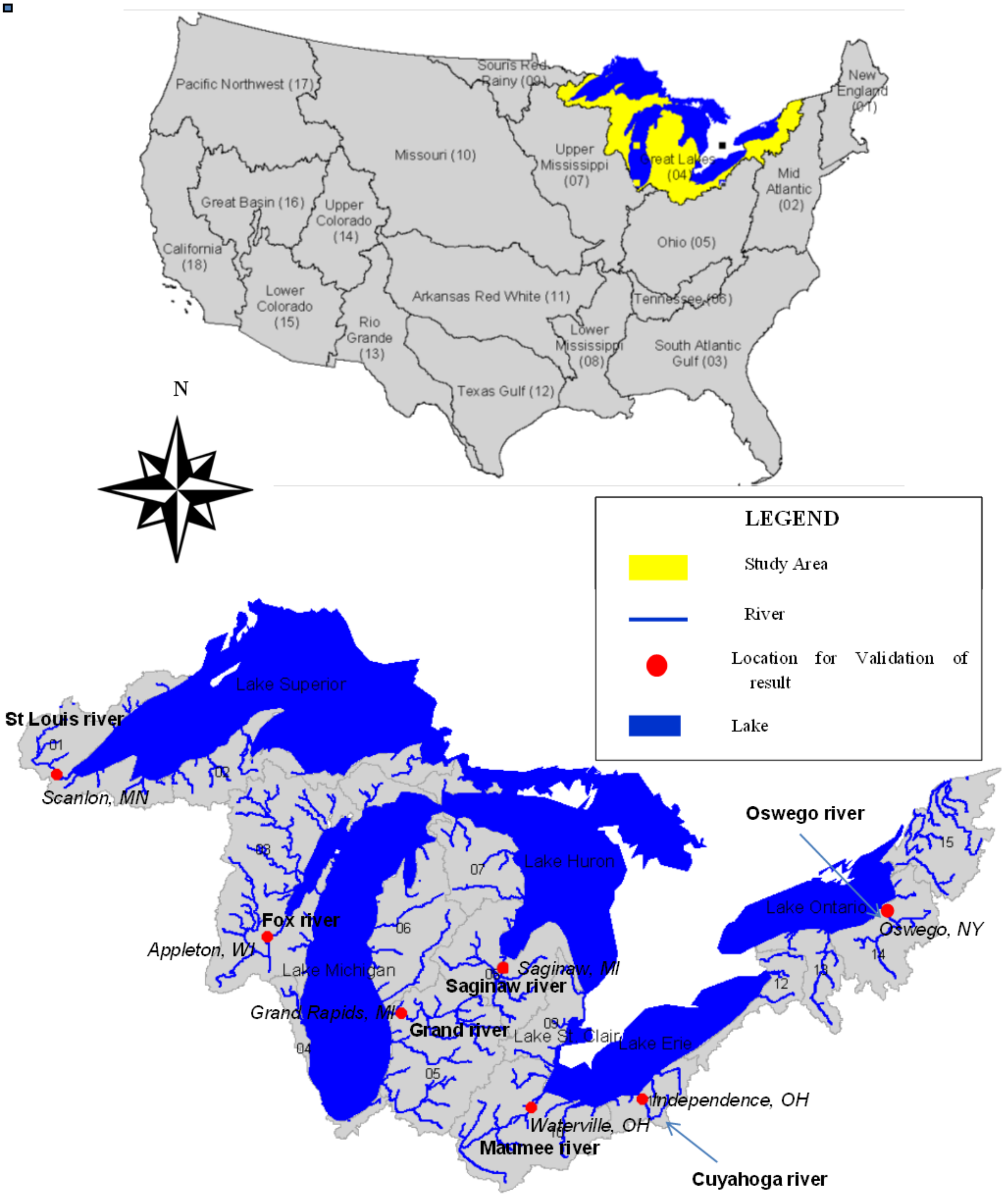


Figure 6-2 Average annual water yield of all 8-digit watersheds in the Great Lakes river basin from cultivated and non-cultivated area (combined water yield from APEX and SWAT)

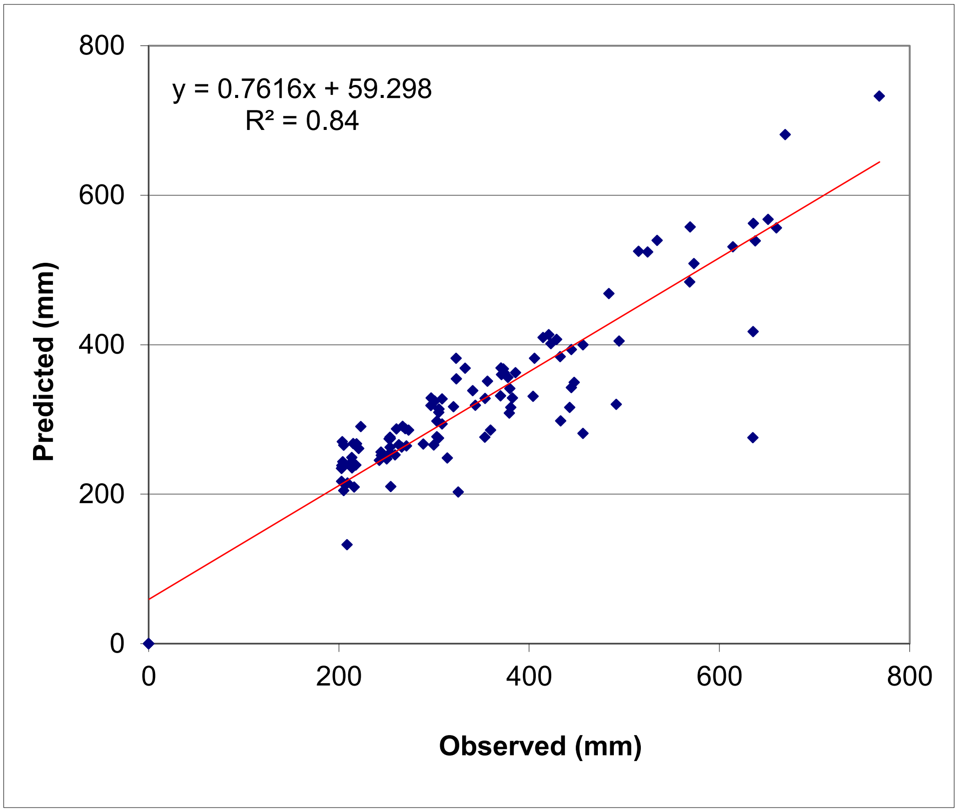


Figure 6-3 Percentage difference between predictions and observations of annual average flow in the GLRB (combined water yield from APEX and SWAT after calibration

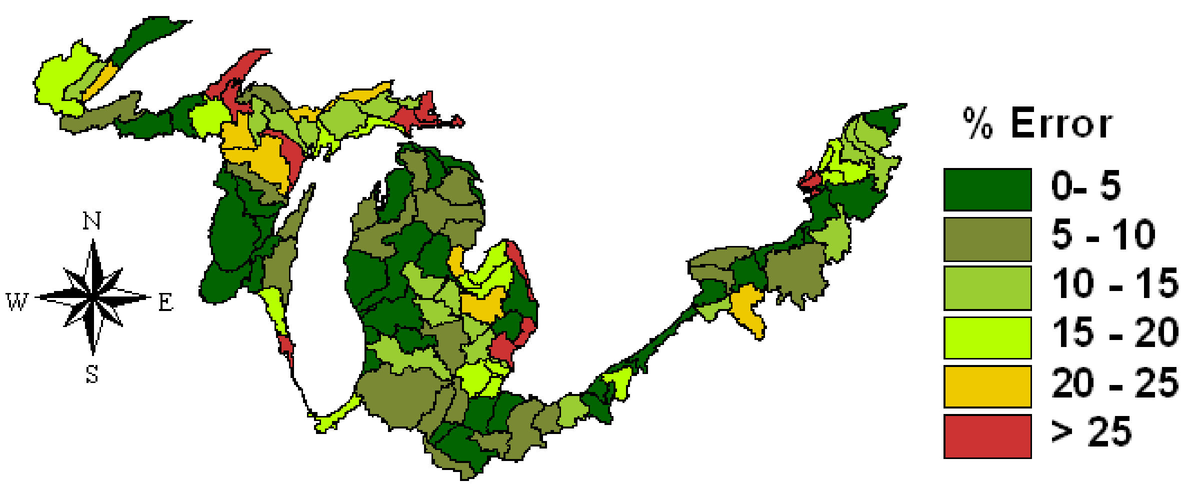


Figure 6-4 Average annual stream flow for the Great Lakes river basin-Calibration period

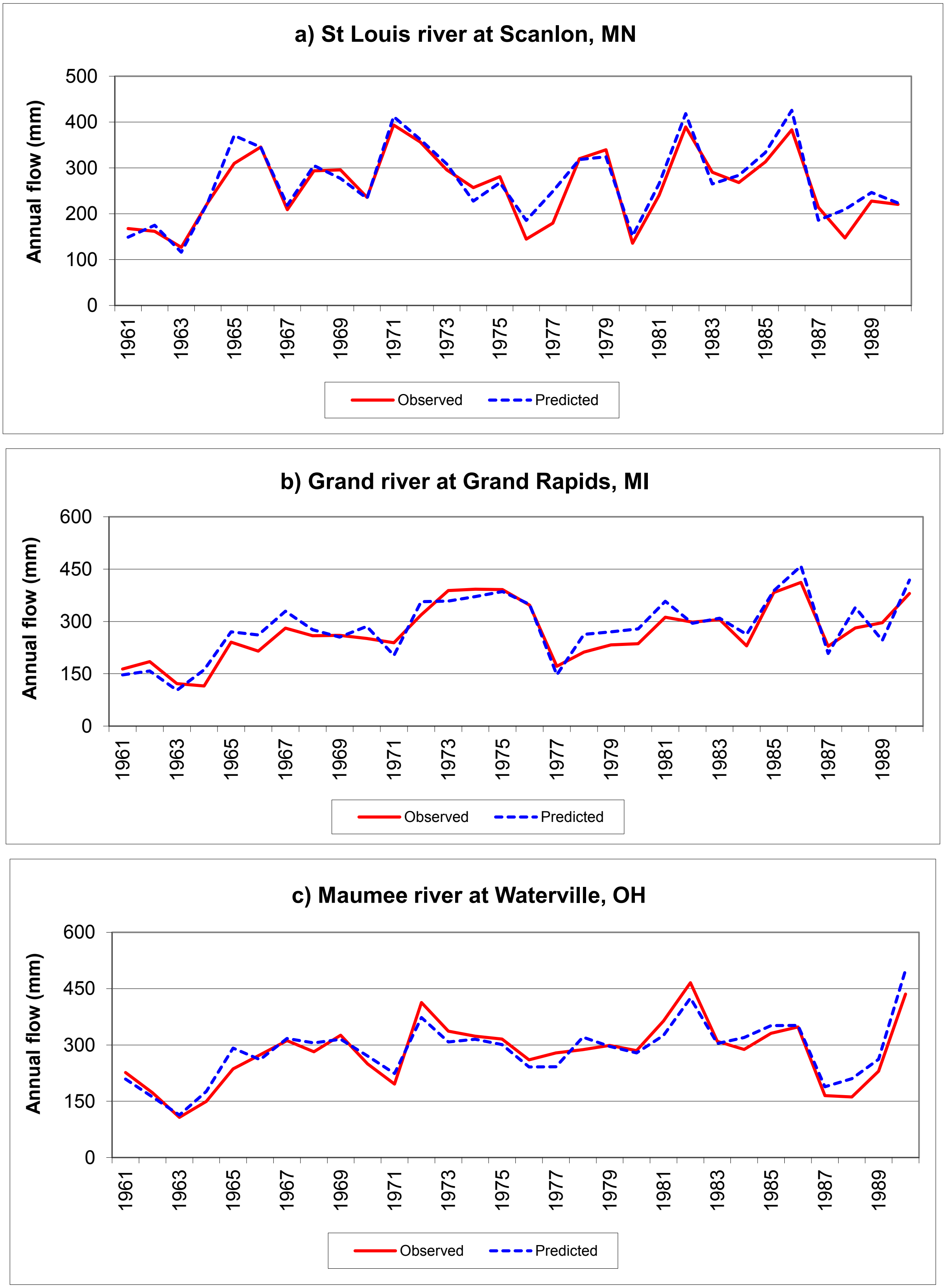


Figure 6-5 Average monthly stream flow for the Great Lakes river basin-Calibration period

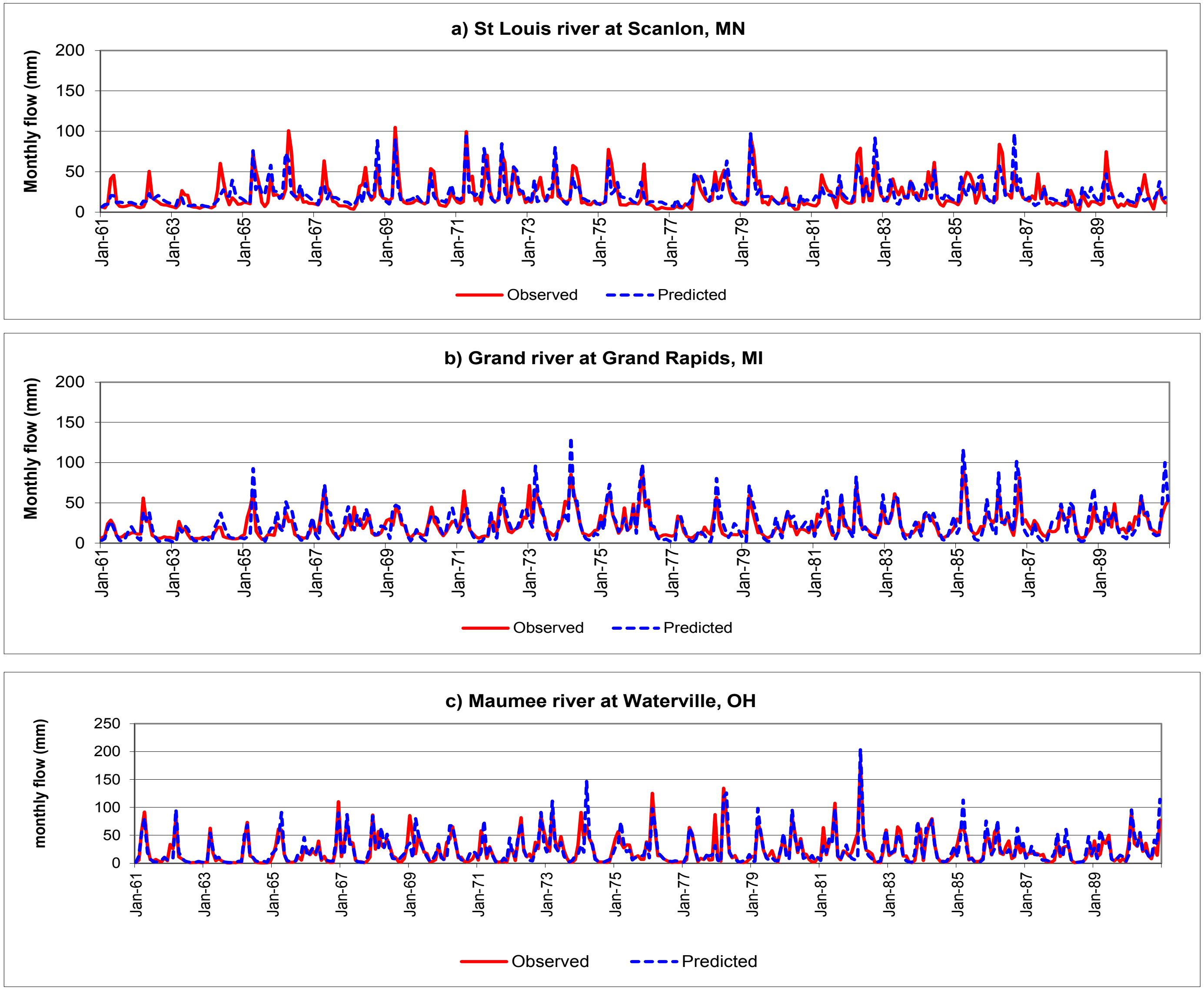


Figure 6-6 Average annual stream flow for the Great Lakes river basin-Validation period

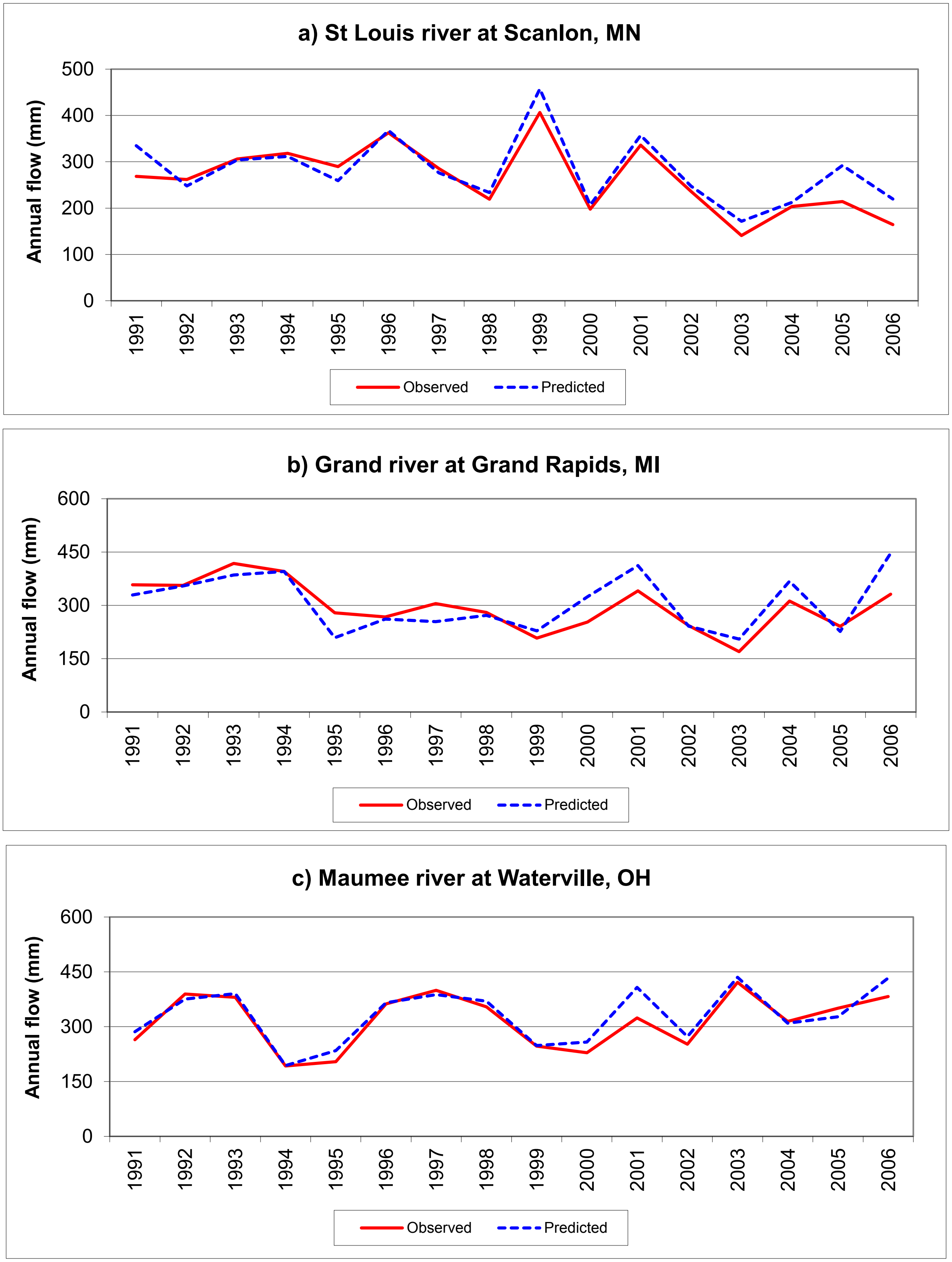


Figure 6-7 Average monthly stream flow for the Great Lakes river basin-Validation period

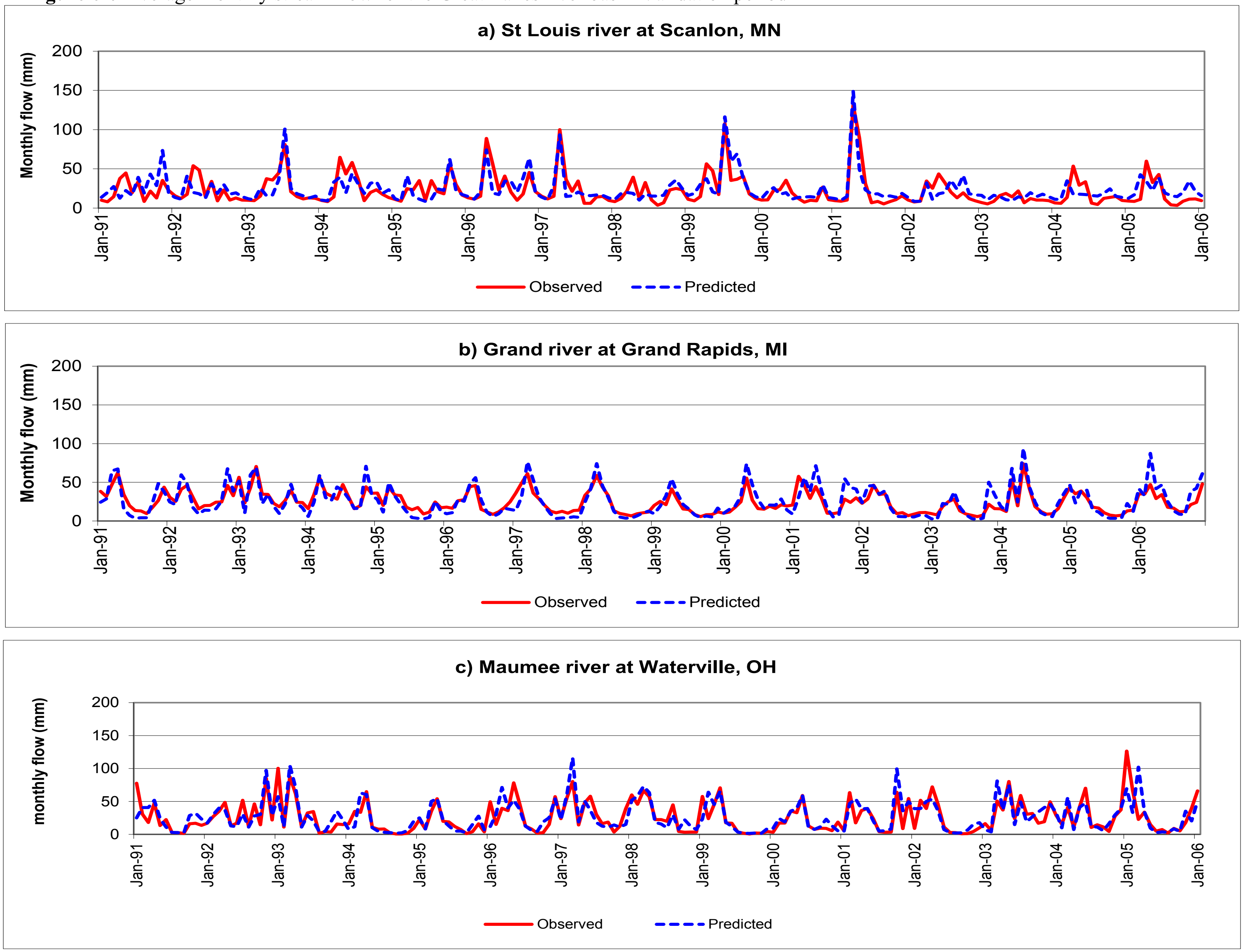


Table 6-2 Mean and standard deviation of the predicted and observed annual and monthly stream flow at selected gauging stations for the calibration period (1961-1990)

	Scanlon, MN	**Grand Rapids, MI**	**Waterville, OH**	**Oswego, NY**
Gauge details				
River	St Louis river	Grand river	Maumee river	Oswego river
River reach-HUC	04010201	04050006	04100009	04140203
Drainage area (Km^2)	8,883.7	15,240.0	16,394.6	13,208.9
Data availability (period)	1961-1990	1961-1990	1961-1990	1969-1990
Mean flow (mm)				
Annual-Predictions	269.3	283.7	285.3	442.7
Annual-Observations	259.0	271.6	281.0	464.5
Monthly-Predictions	22.4	23.6	23.8	36.9
Monthly-Observations	21.6	22.6	23.4	38.7
Standard deviation (mm)				
Annual-Predictions	81.6	87.5	78.1	114.6
Annual-Observations	78.8	81.1	83.7	129.9
Monthly-Predictions	16.1	20.9	27.5	27.1
Monthly-Observations	18.7	16.2	25.7	25.8

Table 6-3 Coefficient of determination and efficiency of the predicted and observed annual and monthly stream flow at selected gauging stations for the calibration period (1961-1990)

	Scanlon, MN	**Grand Rapids, MI**	**Waterville, OH**	**Oswego, NY**
Gauge details				
River	St Louis river	Grand river	Maumee river	Oswego river
River reach-HUC	04010201	04050006	04100009	04140203
Drainage area (Km^2)	8,883.7	15,240.0	16,394.6	13,208.9
Data availability (period)	1961-1990	1961-1990	1961-1990	1969-1990
R^2				
Annual	0.90	0.87	0.88	0.93
Monthly	0.55	0.74	0.75	0.80
Nash and Sutcliffe Efficiency				
Annual	0.87	0.82	0.88	0.89
Monthly	0.54	0.54	0.71	0.77

Table 6-4 Mean and standard deviation of the predicted and observed annual and monthly stream flow at selected gauging stations for the validation period (1991-2006)

	Scanlon, MN	Grand Rapids, MI	Waterville, OH	Oswego, NY
Gauge details				
River	St Louis river	Grand river	Maumee river	Oswego river
River reach-HUC	04010201	04050006	04100009	04140203
Drainage area (Km^2)	8,883.7	15,240.0	16,394.6	13,208.9
Data availability (period)	1991-2006	1991-2006	1991-2006	1991-2006
Mean flow (mm)				
Annual-Predictions	281.2	307.1	331.0	485.7
Annual-Observations	263.2	297.4	316.6	496.7
Monthly-Predictions	23.4	25.6	27.6	40.5
Monthly-Observations	21.9	24.8	26.4	41.4
Standard deviation (mm)				
Annual-Predictions	73.0	79.4	75.2	116.6
Annual-Observations	72.8	67.6	74.8	118.0
Monthly-Predictions	18.3	19.9	23.5	26.7
Monthly-Observations	19.8	14.4	23.5	27.5

Table 6-5 Coefficient of determination and efficiency of the predicted and observed annual and monthly stream flow at selected gauging stations for the validation period (1991-2006)

	Scanlon, MN	Grand Rapids, MI	Waterville, OH	Oswego, NY
Gauge details				
River	St Louis river	Grand river	Maumee river	Oswego river
River reach-HUC	04010201	04050006	04100009	04140203
Drainage area (Km^2)	8,883.7	15,240.0	16,394.6	13,208.9
Data availability (period)	1991-2006	1991-2006	1991-2006	1991-2006
R^2				
Annual	0.83	0.62	0.88	0.83
Monthly	0.60	0.77	0.6.3	0.83
Nash and Sutcliffe Efficiency				
Annual	0.76	0.53	0.85	0.79
Monthly	0.57	0.51	0.59	0.83

Figure 6-8 Average annual sediment load for Great Lakes river basin

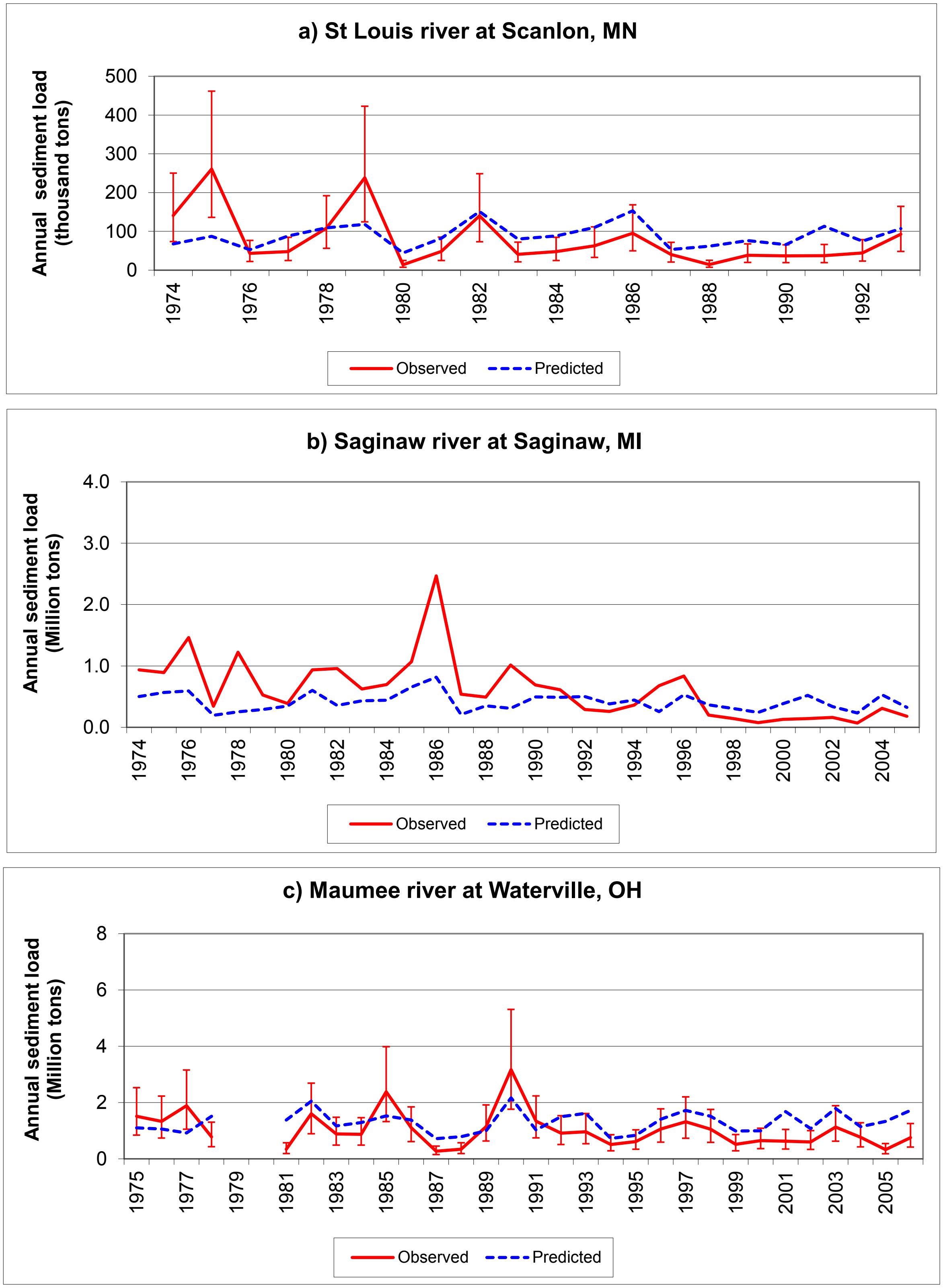
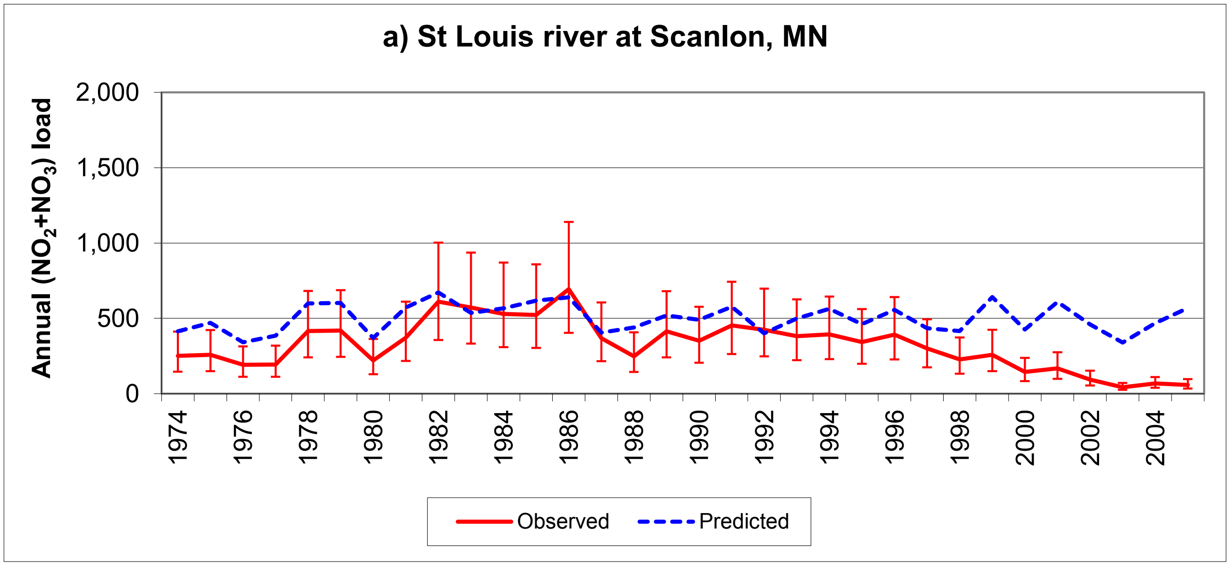


Figure 6-9 Average annual nitrite and nitrate Nitrogen (NO_2+NO_3) load for the Great Lakes river basin



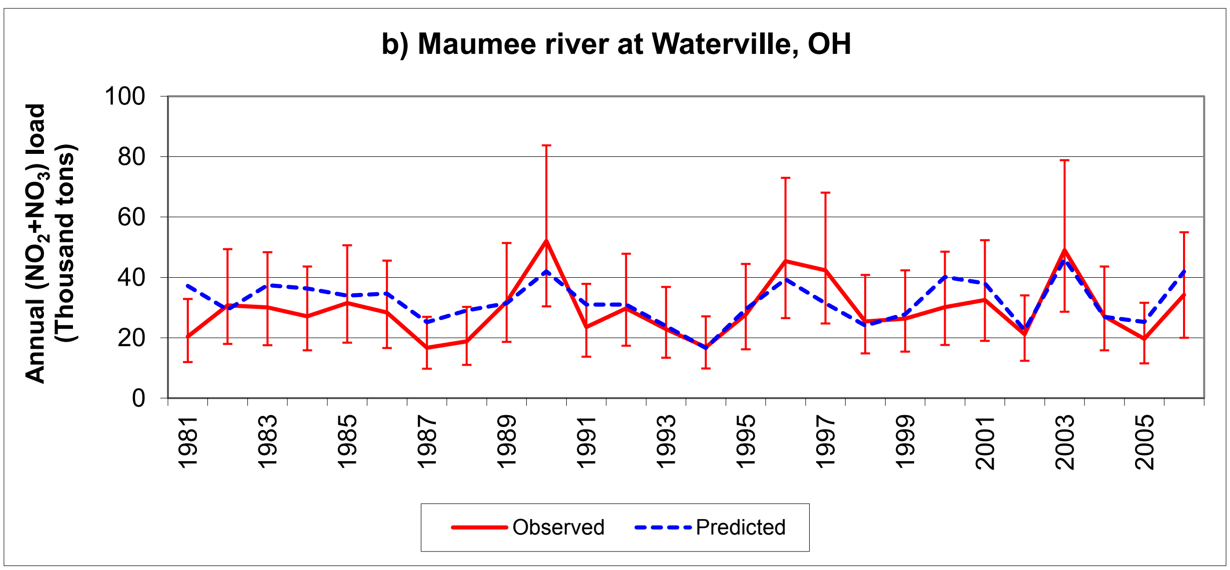
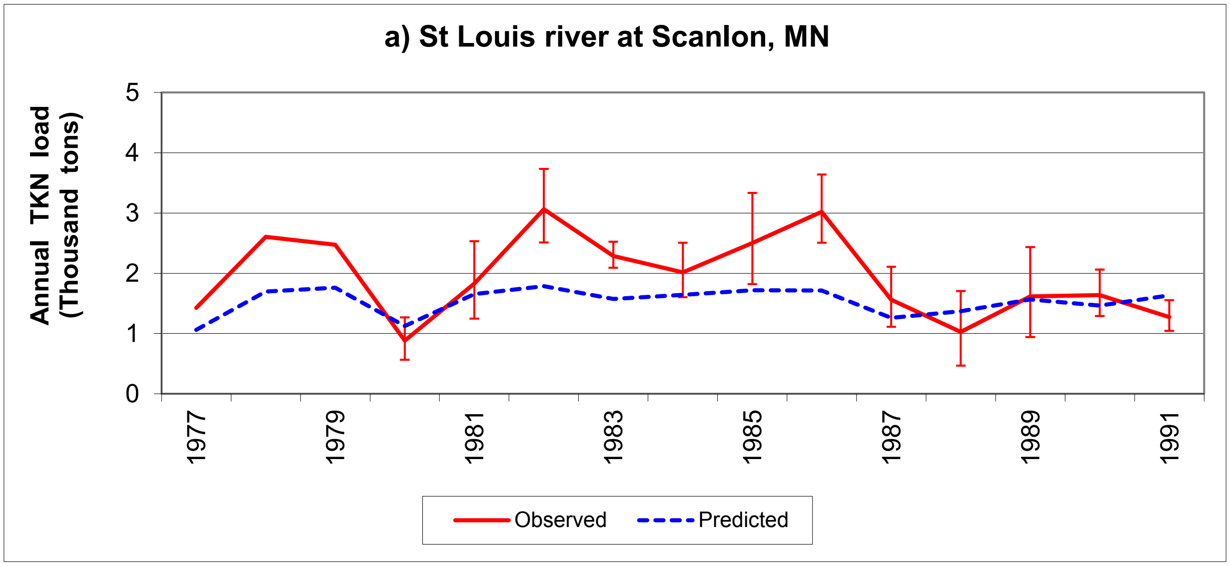


Figure 6-10 Average annual total Kjeldahl Nitrogen (TKN) load for the Great Lakes river basin



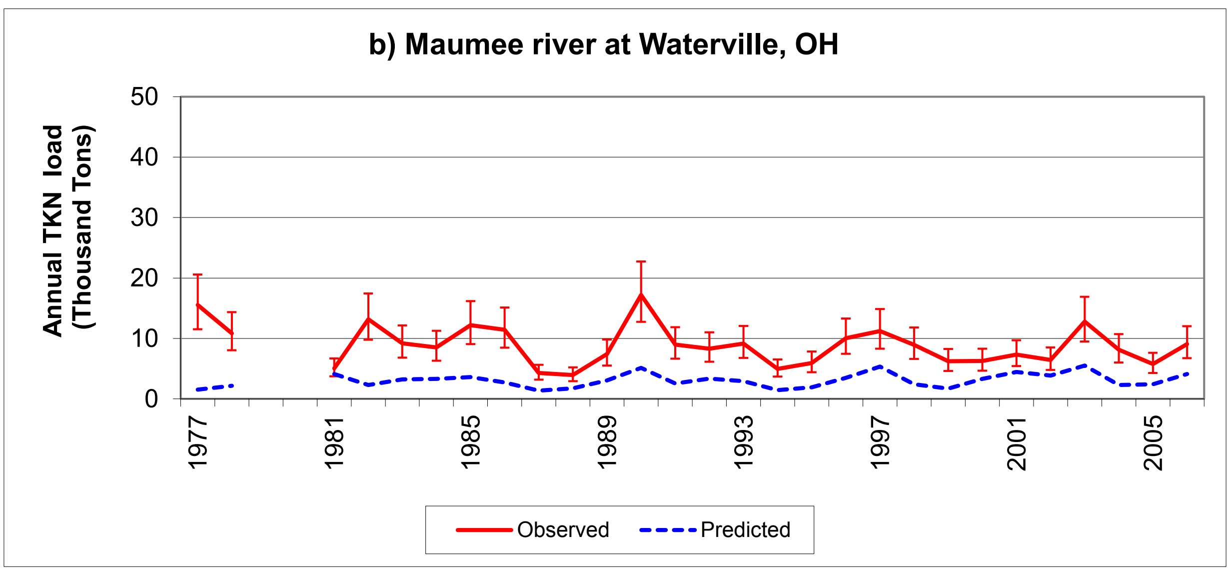


Figure 6-11 Average annual total Nitrogen (TN) load for the Great Lakes river basin

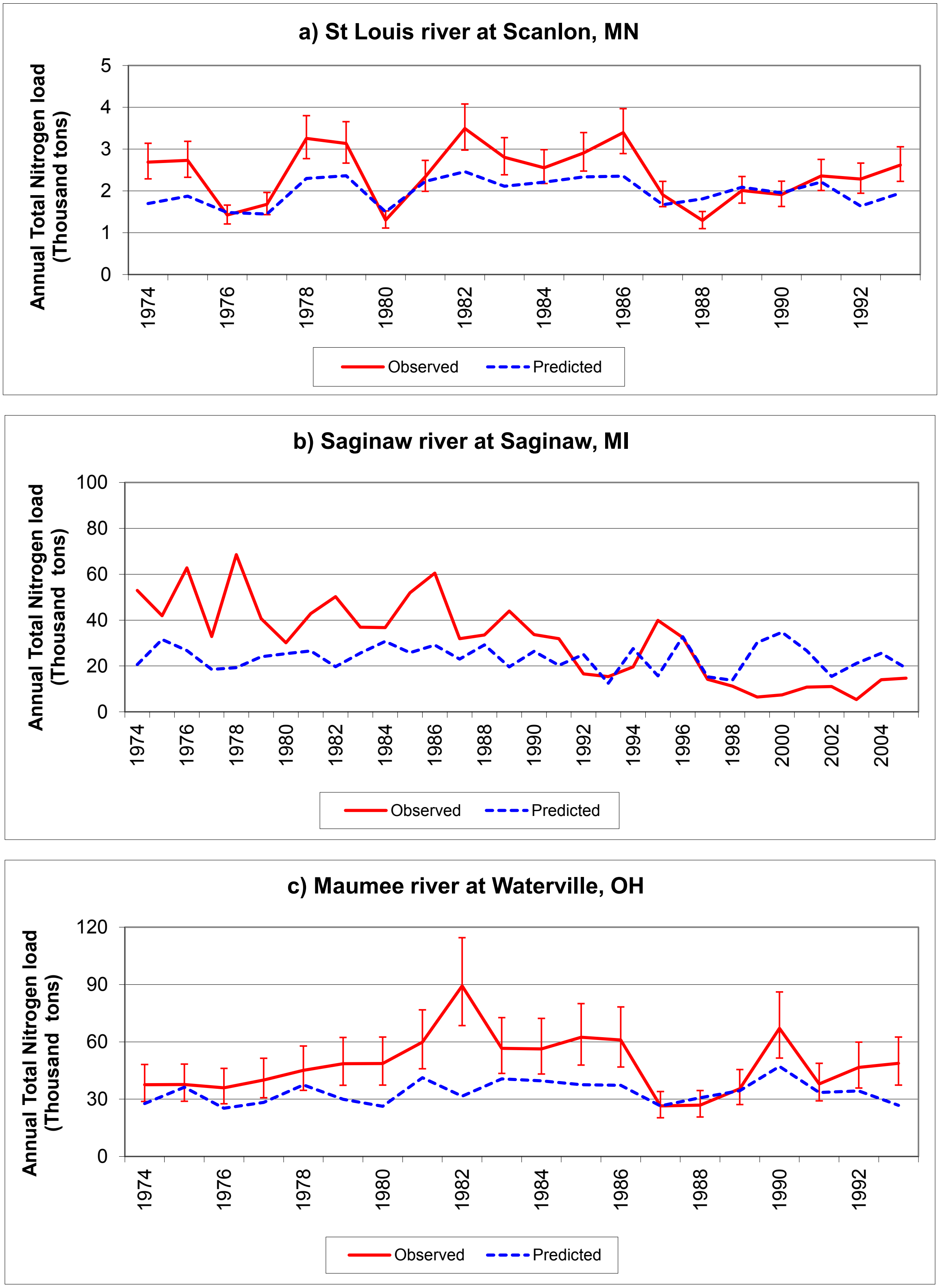


Figure 6-12 Average annual total Phosphorus (TP) load for the Great Lakes river basin

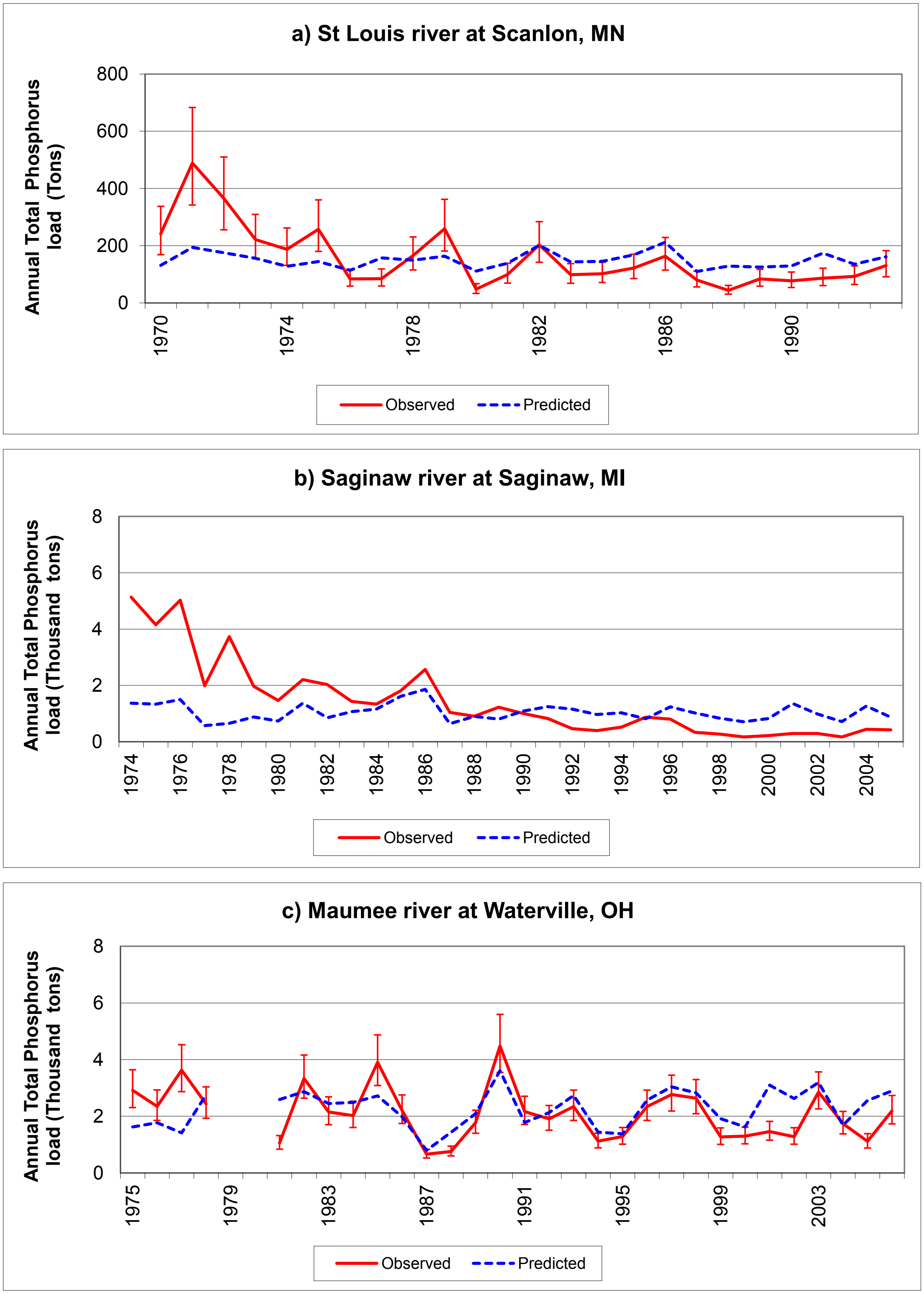
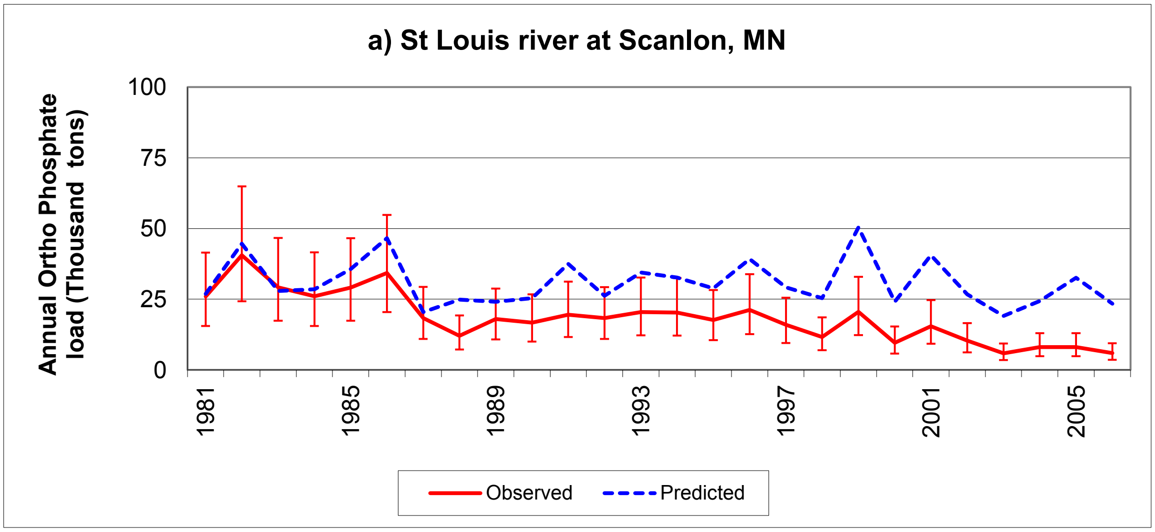


Figure 6-13 Average annual Ortho Phosphate (Ortho P) load for the Great Lakes river basin



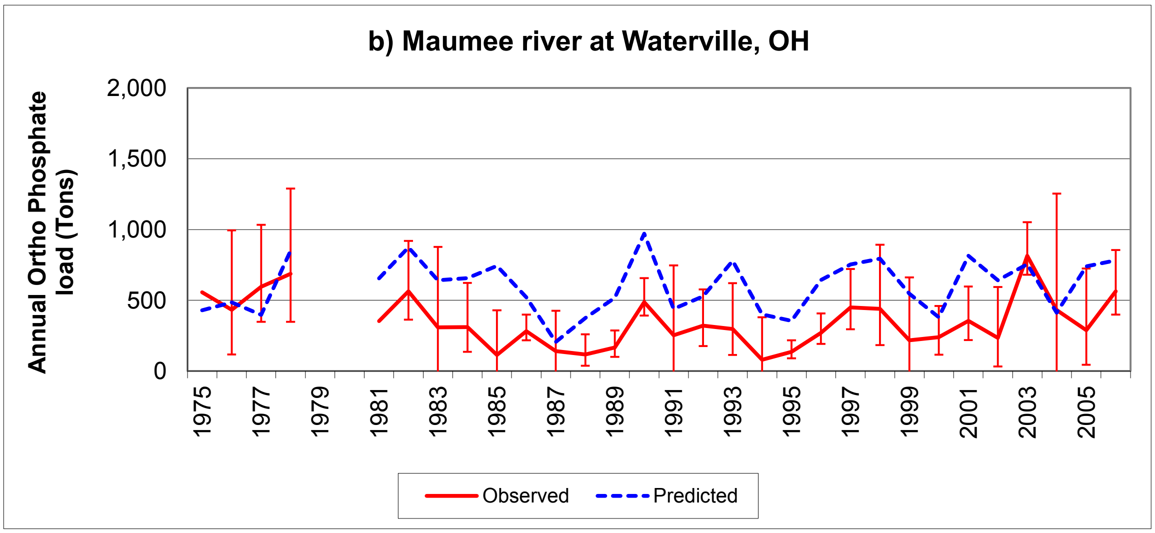


Figure 6-14 Average annual soluble Atrazine load for the Great Lakes river basin

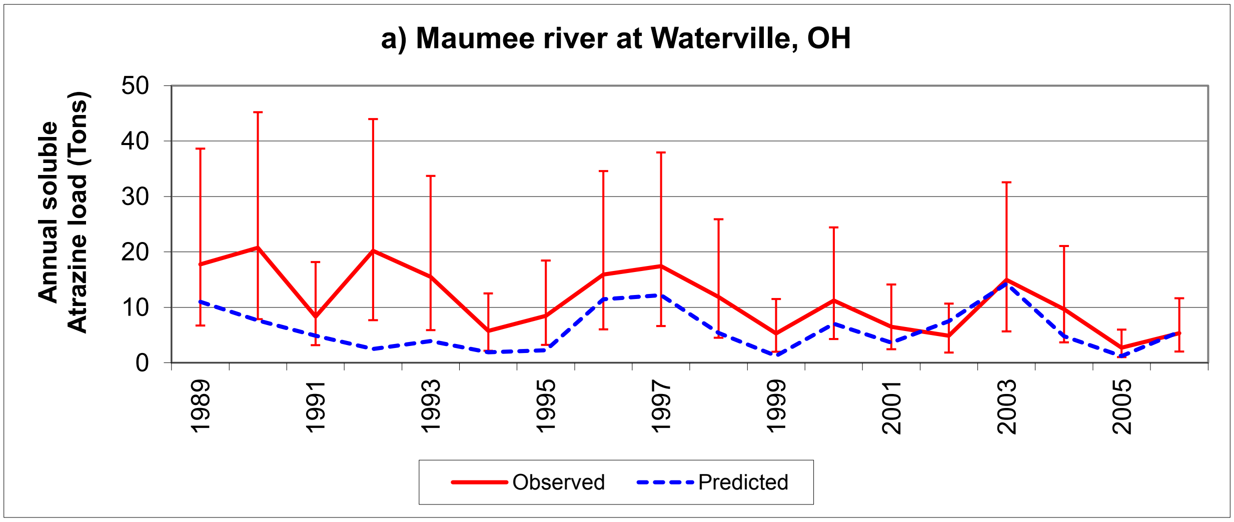


Table 6-6 Average annual Suspended Sediment load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
St Louis river at Scanlon, MN	04010201	89,200	79,600
Fox river at Appleton, WI	04030204	62,240	59,108
Saginaw river at Saginaw, MI	04080206	413,338	614,585
Maumee river at Waterville, OH	04100009	1,330,021	1,024,389
Cuyahoga river at Independence, OH	04110002	116,448	204,084

Table 6-7a Average annual Nitrate and Nitrite Nitrogen load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
St Louis river at Scanlon, MN	04010201	510	310
Fox river at Appleton, WI	04030204	697	611
Saginaw river at Saginaw, MI	04080206	-----	-----
Maumee river at Waterville, OH	04100009	31,981	29,284
Cuyahoga river at Independence, OH	04110002	1,721	1,519

Table 6-7b Average annual total Kjeldahl Nitrogen load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
St Louis river at Scanlon, MN	04010201	1,538	1,948
Fox river at Appleton, WI	04030204	-----	-----
Saginaw river at Saginaw, MI	04080206	-----	-----
Maumee river at Waterville, OH	04100009	3,042	8,867
Cuyahoga river at Independence, OH	04110002	1,898	1,007

Table 6-7c Average annual total Total Nitrogen load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
St Louis river at Scanlon, MN	04010201	1,983	2,403
Fox river at Appleton, WI	04030204	2,348	4,972
Saginaw river at Saginaw, MI	04080206	23,676	31,341
Maumee river at Waterville, OH	04100009	33,635	48,432
Cuyahoga river at Independence, OH	04110002	-----	-----

Table 6-8a Average annual Total Phosphorus load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
St Louis river at Scanlon, MN	04010201	150	158
Fox river at Appleton, WI	04030204	139	269
Saginaw river at Saginaw, MI	04080206	1,045	1,422
Maumee river at Waterville, OH	04100009	2,269	2,114
Cuyahoga river at Independence, OH	04110002	210	274

Table 6-8b Average annual Ortho Phosphate load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
St Louis river at Scanlon, MN	04010201	31	18
Fox river at Appleton, WI	04050006	23	24
Saginaw river at Saginaw, MI	04080206	-----	-----
Maumee river at Waterville, OH	04100009	603	351
Cuyahoga river at Independence, OH	04110002	109	42

Table 6-9 Average daily Atrazine load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Maumee river at Waterville, OH	04100009	6.0	11.3

Chapter 7

Calibration and Validation of CEAP-HUMUS for the Missouri River Basin

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Chapter 7 describes results of calibration and validation of CEAP-HUMUS model setup for the Missouri River Basin. More details on procedures used in the calibration-validation process are presented in Chapter 1.

(Status: Complete)

This chapter addresses calibrations of APEX and HUMUS/SWAT for the Missouri River Basin (MRB) and to validate the CEAP modeling framework at selected gauging stations.

Annual and monthly flow calibration and validation at stream gages

Eight USGS stream gages were selected in the MRB for annual and monthly flow calibration and validation (Fig 1). Calibration was performed for the period 1961 to 1990 to ensure that there was a reasonable agreement between predicted and observed flow at annual and monthly time steps. The model was validated for annual and monthly flows in the same stream gages for the period 1991 to 2006 without changing the calibrated input parameters. Missouri River and its tributaries are impounded by several reservoirs throughout the basin. To improve the simulated flow and water quality results from the model setup, observed mean reservoir outflow data at monthly time step were read into the model.

Calibration results of the average annual runoff at 8-digit watersheds

Average annual water yield from cultivated and non-cultivated land

The average annual simulated and targeted runoff of the 8-digit watersheds in the Missouri River basin is shown in Figure 7-2. Targeted and simulated runoff patterns concur with the precipitation patterns of this watershed. The regression relationship between targeted and simulated runoff at 8-digit watersheds (R2 is 0.90), the means and standard deviations of annual runoff (of all the 8-digit watersheds in the basin) indicate that the model prediction is satisfactory (Figure 7-3 and Table 7-1). All the 8-digit watersheds except 20 were within the stipulated calibration goal of less than 20 % difference between predictions and target values of average annual water yield (Fig. 3).

Annual and monthly flow calibration and validation at stream gages

Flow calibration and validation results at annual and monthly time step are shown in figures F-4 to F-7 and Tables F-2 to F-5 for the stream gages located in Yellowstone river (Sidney-MT), Missouri River (Culbertson-MT, Bismark-ND, Yankston-SD, Omaha-NE and Hermann-MO), Platte river (Louisville-NE), Osage river (St Thomas, MO).

Observed and simulated flows at annual and monthly time steps matched very well for the calibration period (figures F-4 and F-5). Means and standard deviations of predictions and observations are in close agreement (Table 7-2). In addition, the coefficient of determination is greater than 0.6 (R2) and NSE is greater than 0.5 (Table 7-3) for most of the gauges during the calibration period.. In summary, during calibration period, the model performance evaluation measures suggest an overall good agreement between observed and simulated flows at the annual and monthly time step, throughout the river basin.

Annual and monthly flow results for the above listed gauging stations for validation period are shown in (Figure 7-6, and F-7 and tables F-4 and F-5). Based on R2 and NSE it can be seen that most of the gauges show acceptable predicted results from model. In summary, HUMUS-SWAT is able to capture the annual and monthly flow patterns very well in the Tennessee river basin.

Sediment calibration

Predicted sediment results were validated in six different gauging stations (Fig F-1) in TRB as outlined in Table 7-6. To limit the contents of this section, detailed results are shown only for three locations. However, the means are shown for all stations (Table 7-6). Fig. F-8 shows a detailed comparison of predicted and target sediment loads in Yellowstone river at Sidney, MT, Missouri River at Omaha, NE and Hermann, MO (Table 7-6, Fig. F-8) of annual sediment loads. For all the gauging stations analyzed, there is close match between predictions and target values of sediment load (Fig. F-8). However, there is under-estimation of sediment in Platte river at Louisville, NE. High predicted sediment deposition in the reaches and reservoirs could be the possible reasons. However, considering the quality of predicted sediment loads in all the places of validation, we could say the model results are good enough for making scenario trials.

Nutrient Calibration

Predicted nutrient results were validated in eight gauging stations (Fig. F-1) in MRB as outlined in Tables F-7, and Table 7-8. To limit the number of figures detailed nutrient results are shown for three stations only. However, the predicted and target means are shown for all the stations (Table 7-7 and Table 7-8). Figures F-9 through F-13 show a detailed comparison of predicted and target nutrient loads (various constituents of N and P) in Yellowstone river at Sidney-MT, Missouri River at Omaha-NE and Hermann-MO. Error bars or the upper and lower confidence levels of target values are also presented. In general, the predicted nutrient loads from HUMUS-SWAT are in good agreement with the target values and within the uncertainty limits of target values for most of the nutrient constituent-location combinations (except NH3 and (NO2+NO3) nitrogen for Missouri at Yankston-SD and NH3 for Platte river at Louisville, NE and TKN for Osage river at St Thomas). The nitrogen problem in Platte river could result form overestimation of flow. The possible reasons for over estimation of TKN at Osage river could come from slight overestimation of flow which could have caused increased sediment and increased organic nitrogen.

Table 7-1 Basin-average statistics for predicted and target annual water yield for all 8-digit watersheds in the Missouri River Basin —Combined water yield results from APEX and SWAT after calibration (1961–90)

Calibration	Statistic	Value
Predictions (After calibration)	Mean (mm) Standard deviation (mm)	85.8 110.6
Observations	Mean (mm) Standard deviation (mm)	89.4 137.4

Figure 7-1 Location of the Missouri River basin and sampling locations

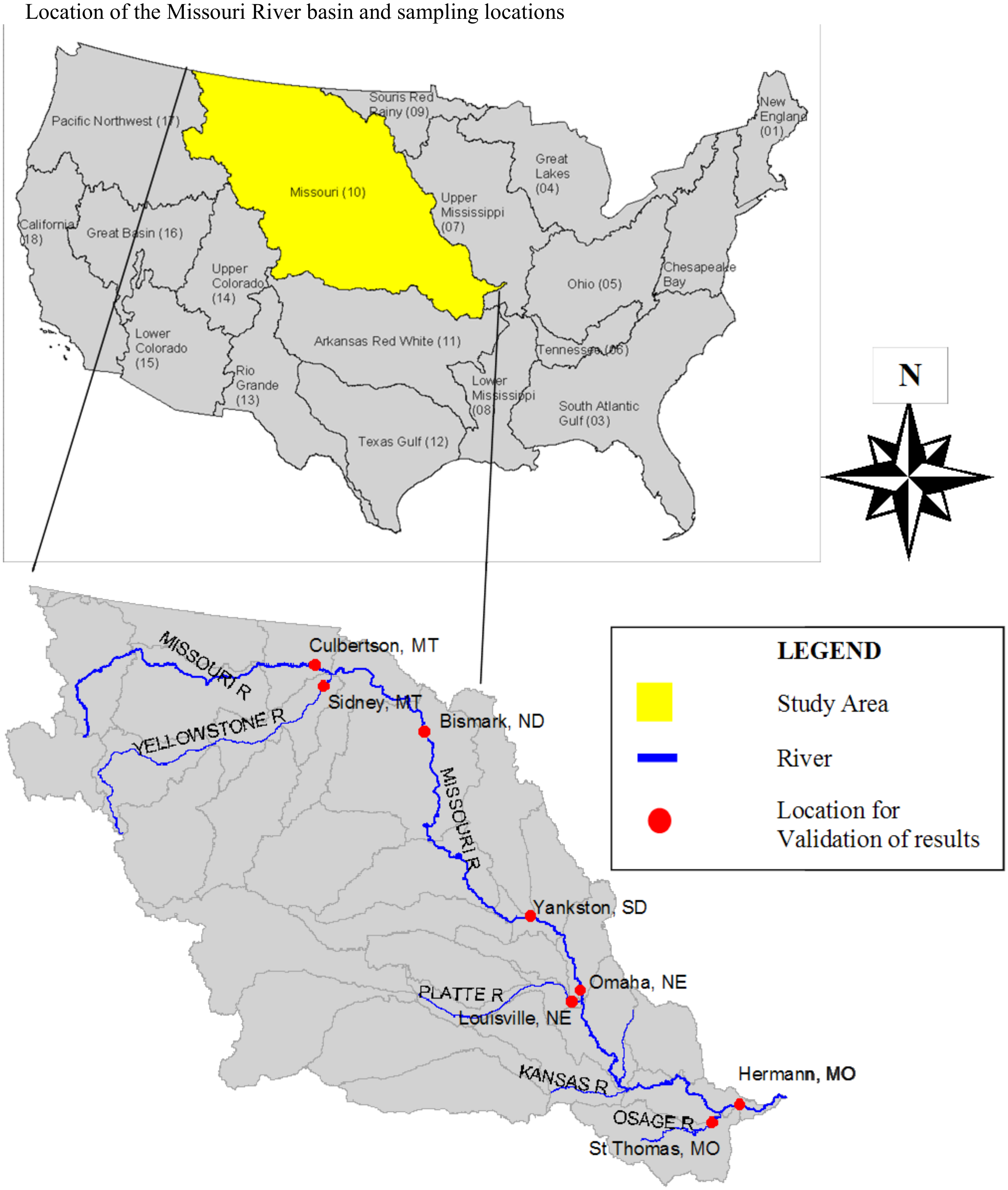


Figure 7-2 Average annual water yield of all 8-digit watersheds in the Missouri River basin from cultivated and non-cultivated area (combined water yield from APEX and SWAT)

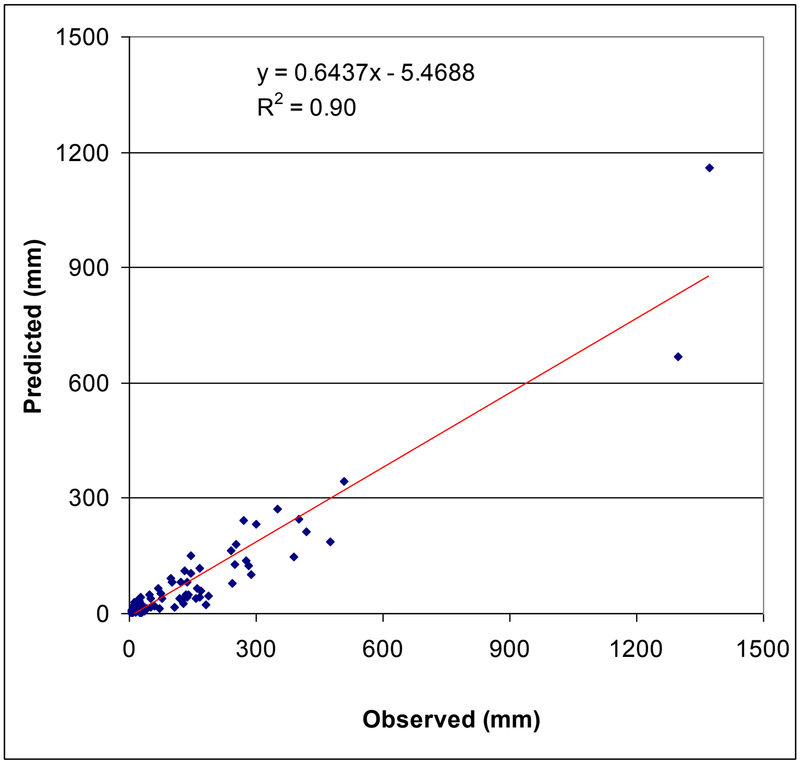


Figure 7-3 Prediction of average annual flow in the Mississippi River basin (combined water yield from APEX and SWAT after calibration).

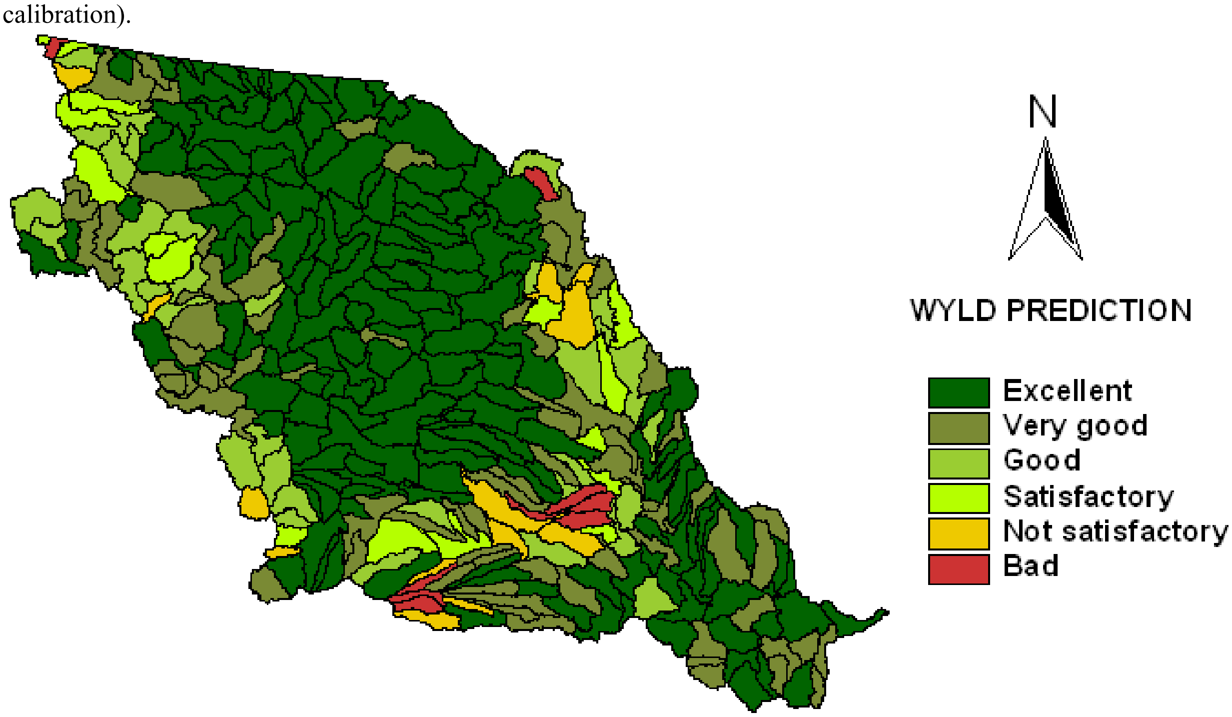


Figure 7-4 Average annual stream flow for the Missouri River basin-Calibration period.

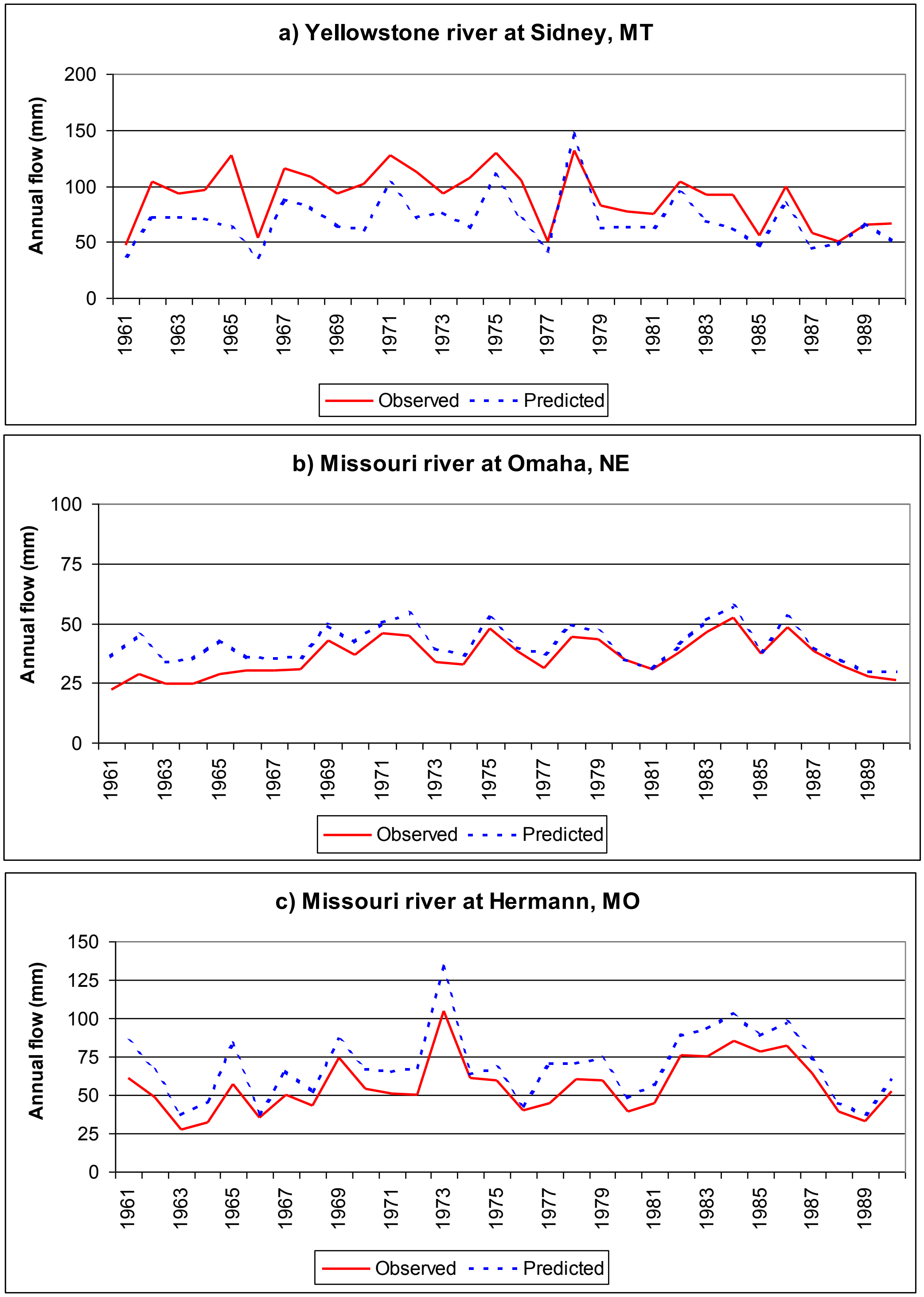


Figure 7-5 Average monthly stream flow for the Missouri River basin-Calibration period

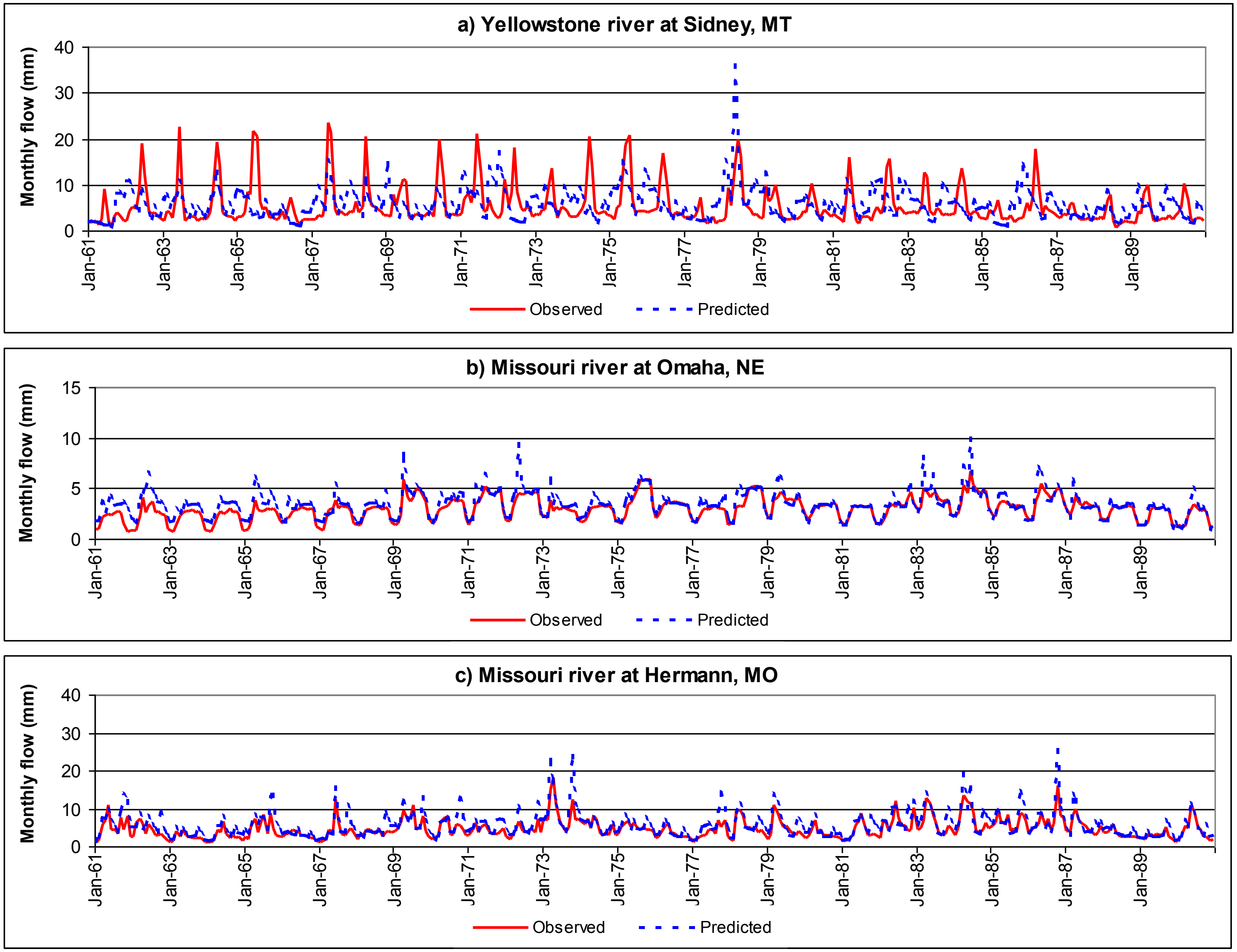
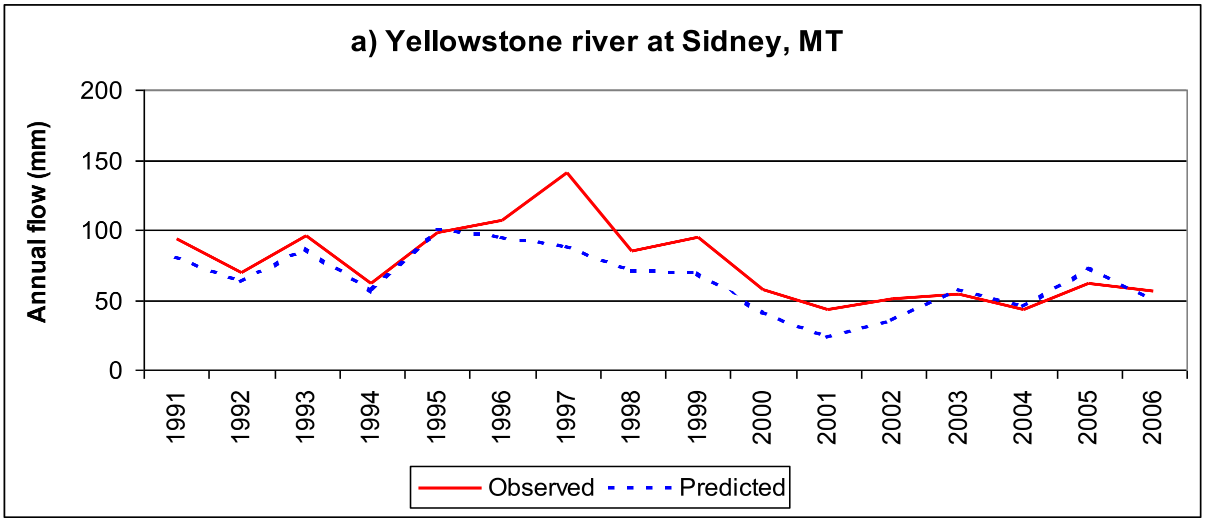
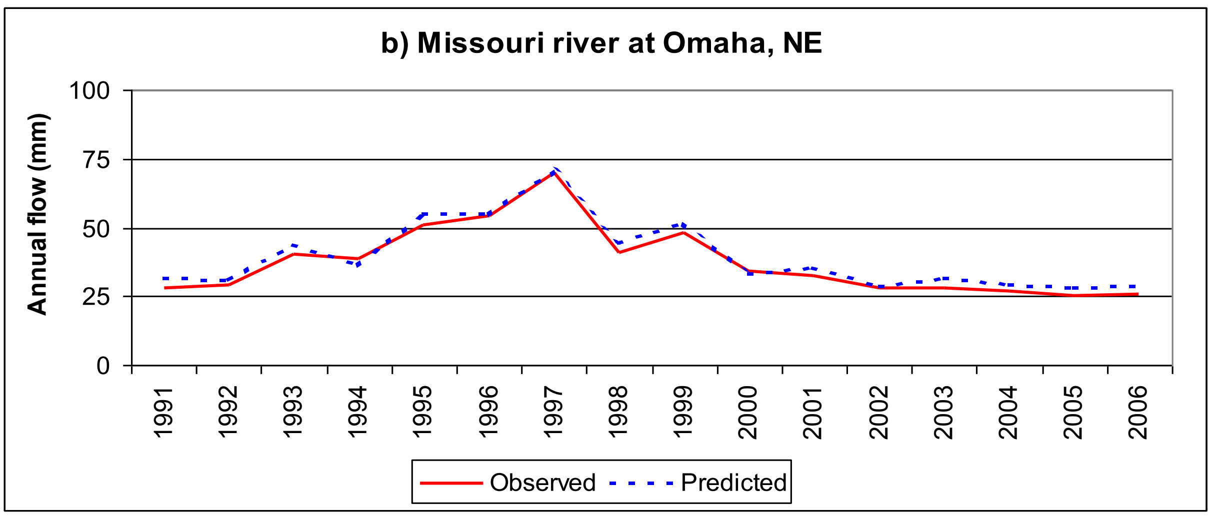


Figure 7-6 Average annual stream flow for the Missouri River basin-Validation period





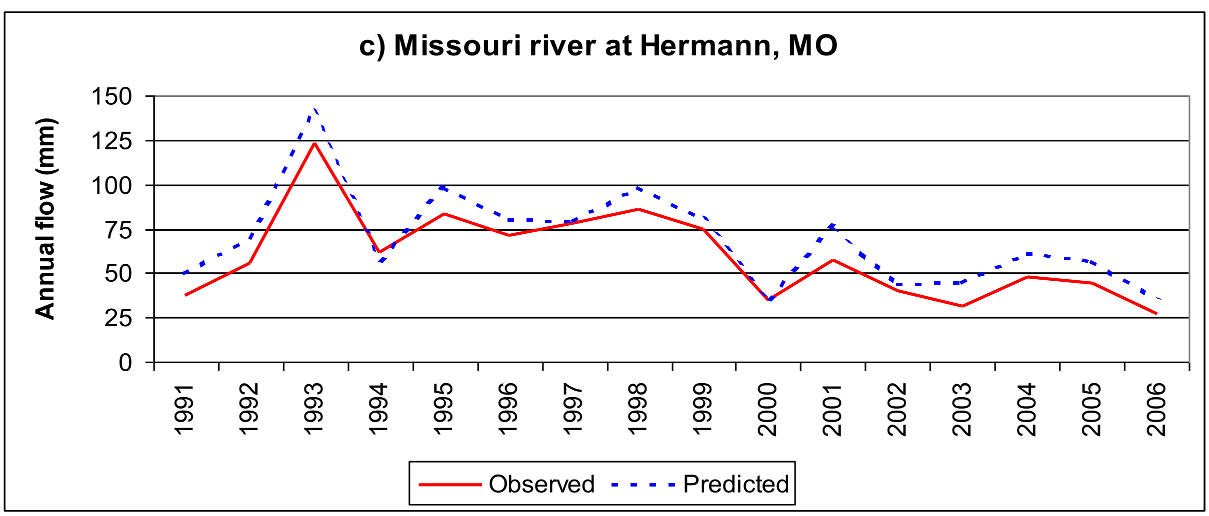


Figure 7-7 Average monthly stream flow for the Missouri River basin-Validation period

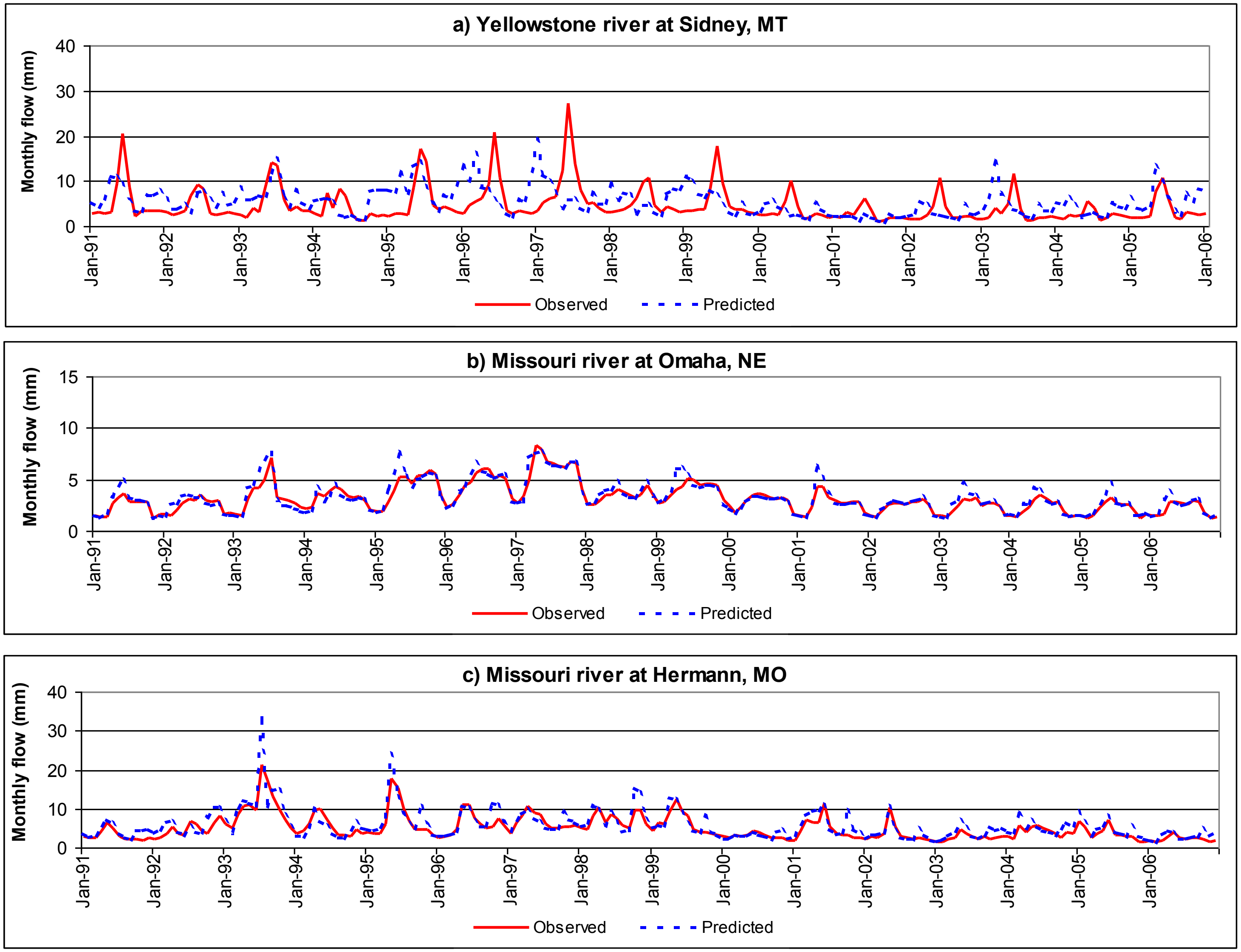


Table 7-2 Mean and standard deviation of the predicted and observed annual and monthly stream flow at selected gauging stations for the calibration period (1961-1990)

	Sidney, MT	**Culbertson, MT**	**Bismark, ND**	**Yankston, SD**	**Omaha, NE**	**Louisville, NE**	**St Thomas, MO**	**Hermann, MO**
Gauge details								
River	Yellowstone	Missouri	Missouri	Missouri	Missouri	Platte	Osage	Missouri
River reach-HUC	10100004	10060005	10130101	10170101	10230006	10200202	10290111	10300200
Drainage area (Km^2)	177,134.5	237,131.5	482,773.8	723,901.6	836,048.1	221,107.3	37,554.8	1,353,268.7
Data availability (period)	1961-1990	1961-1990	1961-1990	1961-1990	1961-1990	1961-1990	1961-1990	1961-1990
Mean flow (mm)								
Annual-Predictions	69.2	46.3	45.7	32.9	41.0	56.4	265.9	68.8
Annual-Observations	90.4	41.6	45.2	34.8	35.7	28.0	263.3	56.0
Monthly-Predictions	5.8	3.9	3.8	2.9	3.4	4.7	22.2	5.7
Monthly-Observations	5.3	3.5	3.8	2.0	3.0	2.3	21.9	4.7
Standard deviation (mm)								
Annual-Predictions	22.9	11.4	8.2	4.0	7.7	24.5	137.7	22.0
Annual-Observations	25.6	10.5	9.6	4.7	8.1	12.3	140.2	18.0
Monthly-Predictions	3.5	1.4	1.0	1.1	1.3	4.1	24.0	3.5
Monthly-Observations	4.3	1.3	1.2	1.6	1.1	1.8	24.3	2.6

Table 7-3 Coefficient of determination and efficiency of the predicted and observed annual and monthly stream flow at selected gauging stations for the calibration period (1961-1990)

	Sidney, MT	**Culbertson, MT**	**Bismark, ND**	**Yankston, SD**	**Omaha, NE**	**Louisville, NE**	**St Thomas, MO**	**Hermann, MO**
Gauge details								
River	Yellowstone	Missouri	Missouri	Missouri	Missouri	Platte	Osage	Missouri
River reach-HUC	10100004	10060005	10130101	10170101	10230006	10200202	10290111	10300200
Drainage area (Km^2)	177,134.5	237,131.5	482,773.8	723,901.6	836,048.1	221,107.3	37,554.8	1,353,268.7
Data availability (period)	1961-1990	1961-1990	1961-1990	1961-1990	1961-1990	1961-1990	1961-1990	1961-1990
R^2								
Annual	0.65	0.99	0.79	0.97	0.75	0.74	0.95	0.92
Monthly	0.09	0.88	0.74	0.90	0.72	0.57	0.51	0.72
Nash and Sutcliffe Efficiency								
Annual	-0.07	0.77	0.79	0.78	0.29	-6.05	0.95	0.32
Monthly	-0.17	0.77	0.74	0.93	0.43	-3.30	0.43	0.32

Table 7-4 Mean and standard deviation of the predicted and observed annual and monthly stream flow at selected gauging stations for the validation period (1991-2006)

	Sidney, MT	**Culbertson, MT**	**Bismark, ND**	**Yankston, SD**	**Omaha, NE**	**Louisville, NE**	**St Thomas, MO**	**Hermann, MO**
Gauge details								
River	Yellowstone	Missouri	Missouri	Missouri	Missouri	Platte	Osage	Missouri
River reach-HUC	10100004	10060005	10130101	10170101	10230006	10200202	10290111	10300200
Drainage area (Km^2)	177,134.5	237,131.5	482,773.8	723,901.6	836,048.1	221,107.3	37,554.8	1,353,268.7
Data availability (period)	1991-2006	1991-2006	1991-2006	1991-1994	1991-2006	1991-2006	1991-1995	1991-2006
Mean flow (mm)								
Annual-Predictions	64.4	34.8	39.0	23.6	39.3	54.1	363.9	68.8
Annual-Observations	75.7	32.9	37.8	24.5	37.5	31.2	373.5	59.6
Monthly-Predictions	5.4	2.9	3.2	2.3	3.3	4.5	27.9	5.7
Monthly-Observations	4.5	2.7	3.1	2.2	3.1	2.6	29.0	5.0
Standard deviation (mm)								
Annual-Predictions	22.3	10.5	11.6	5.2	12.6	24.1	181.2	27.8
Annual-Observations	27.3	9.8	11.0	5.2	12.8	13.1	198.5	25.6
Monthly-Predictions	3.2	1.2	1.3	1.1	1.6	3.9	29.0	3.8
Monthly-Observations	3.9	1.0	1.2	1.0	1.4	1.7	29.5	3.2

Table 7-5 Coefficient of determination and efficiency of the predicted and observed annual and monthly stream flow at selected gauging stations for the validation period (1991-2006)

	Sidney, MT	Culbertson, MT	Bismark, ND	Yankston, SD	Omaha, NE	Louisville, NE	St Thomas, MO	Hermann, MO
Gauge details								
River	Yellowstone	Missouri	Missouri	Missouri	Missouri	Platte	Osage	Missouri
River reach-HUC	10100004	10060005	10130101	10170101	10230006	10200202	10290111	10300200
Drainage area (Km^2)	177,134.5	237,131.5	482,773.8	723,901.6	836,048.1	221,107.3	37,554.8	1,353,268.7
Data availability (period)	1961-1990	1961-1990	1961-1990	1961-1990	1961-1990	1961-1990	1961-1990	1961-1990
R^2								
Annual	0.71	0.97	0.99	1.00	0.98	0.63	0.95	0.95
Monthly	0.09	0.81	0.98	0.82	0.87	0.54	0.55	0.76
Nash and Sutcliffe Efficiency								
Annual	0.53	0.92	0.97	0.99	0.96	-3.75	0.94	0.80
Monthly	-0.26	0.72	0.97	0.98	0.83	-2.89	0.81	0.59

Figure 7-8 Average annual/daily sediment load for Missouri River basin

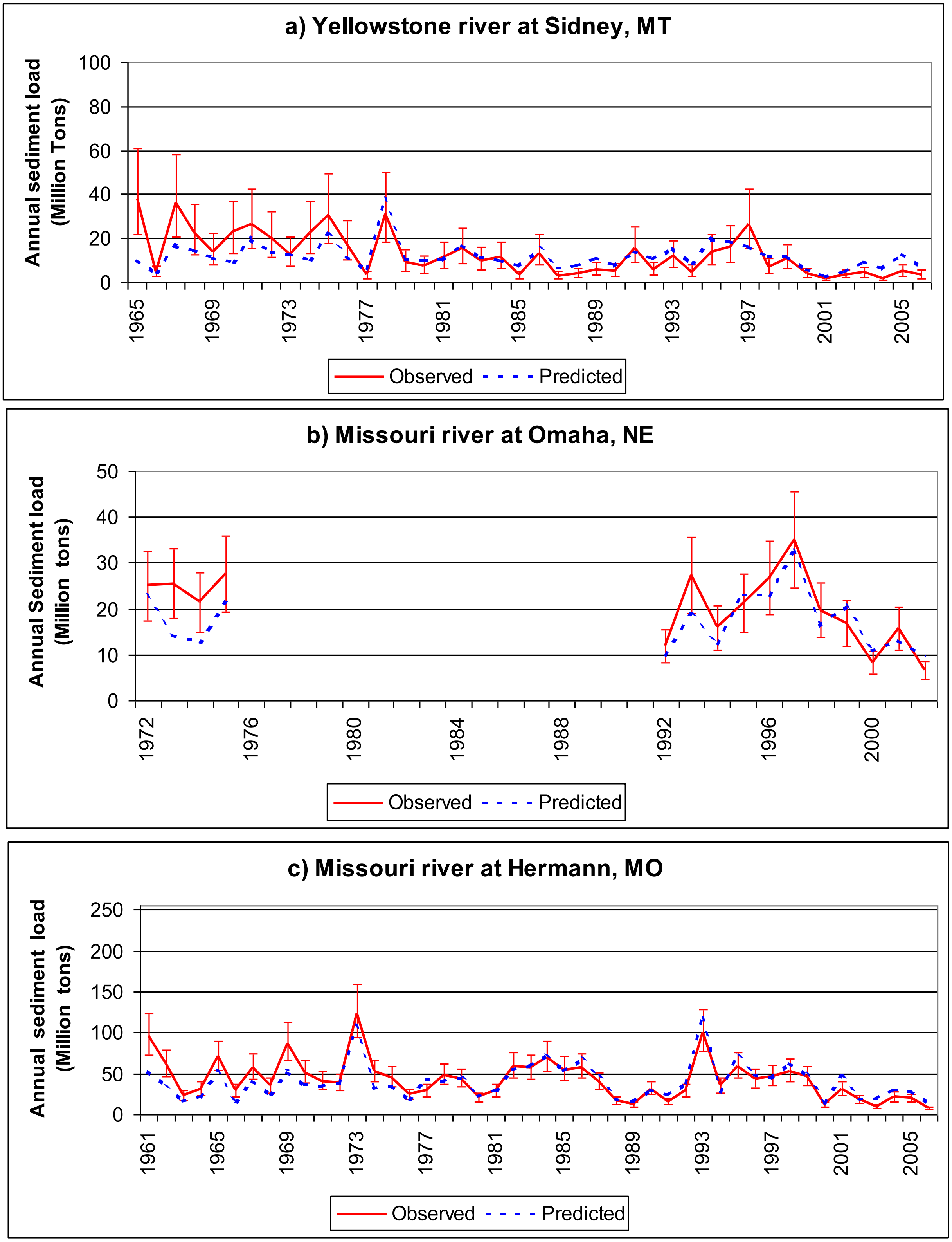


Figure 7-9 Average annual nitrite and nitrate Nitrogen (NO_2+NO_3) load for the Missouri River basin

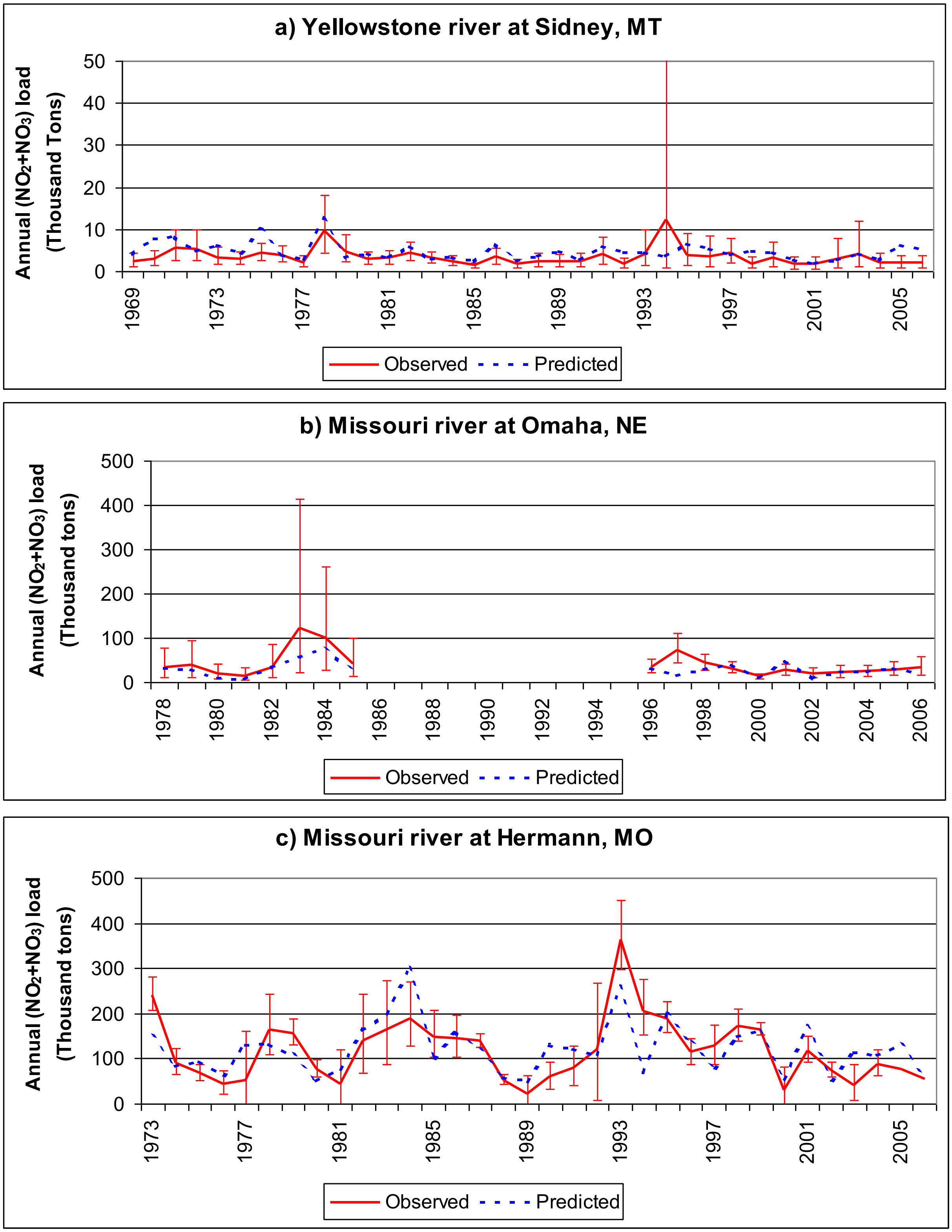


Figure 7-10 Average annual total Kjeldahl Nitrogen (TKN) load for the Missouri River basin

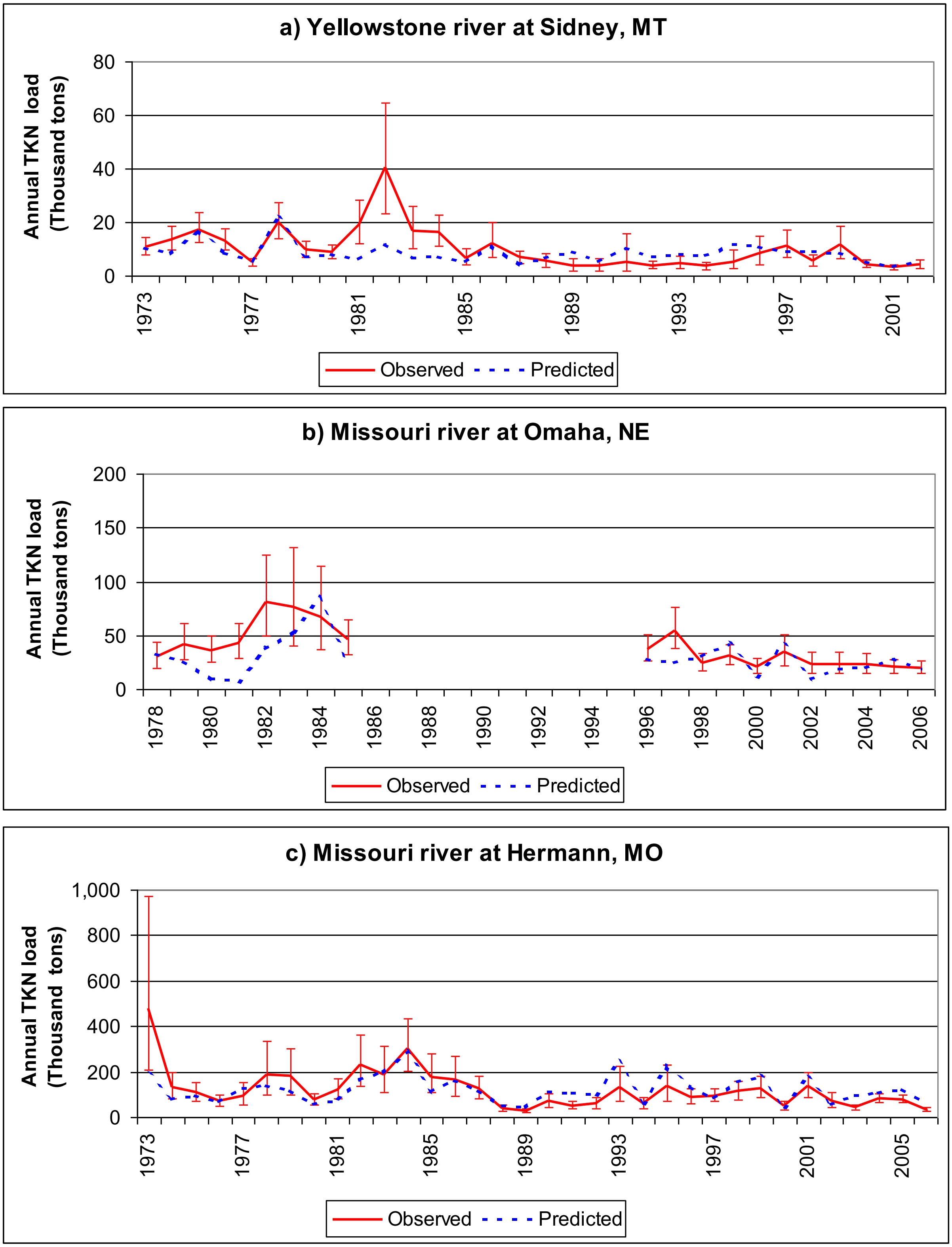


Figure 7-11 Average annual ammonia Nitrogen (NH_3) load for the Missouri River basin

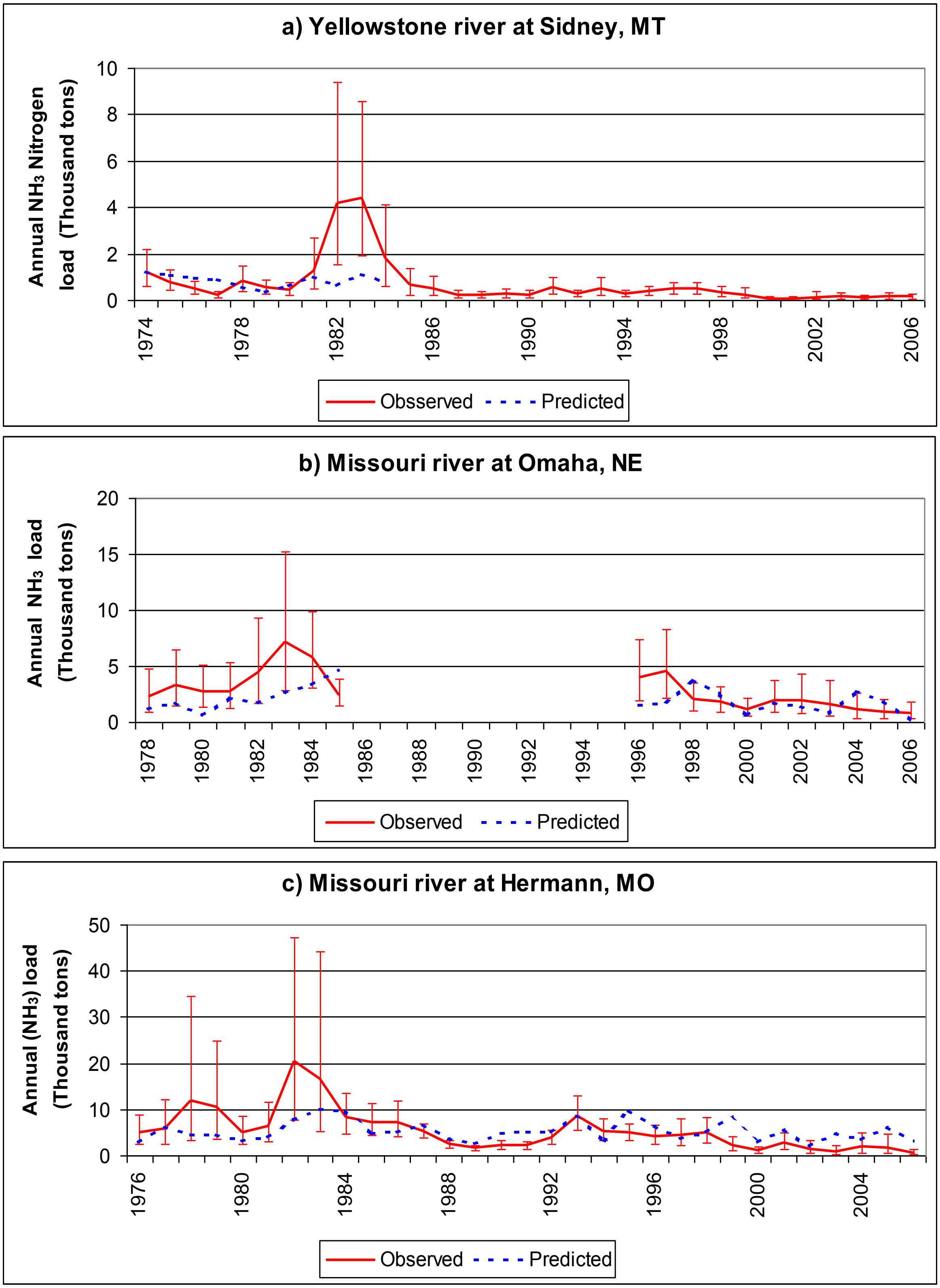


Figure 7-12 Average annual total Phosphorus (TP) load for the Missouri River basin

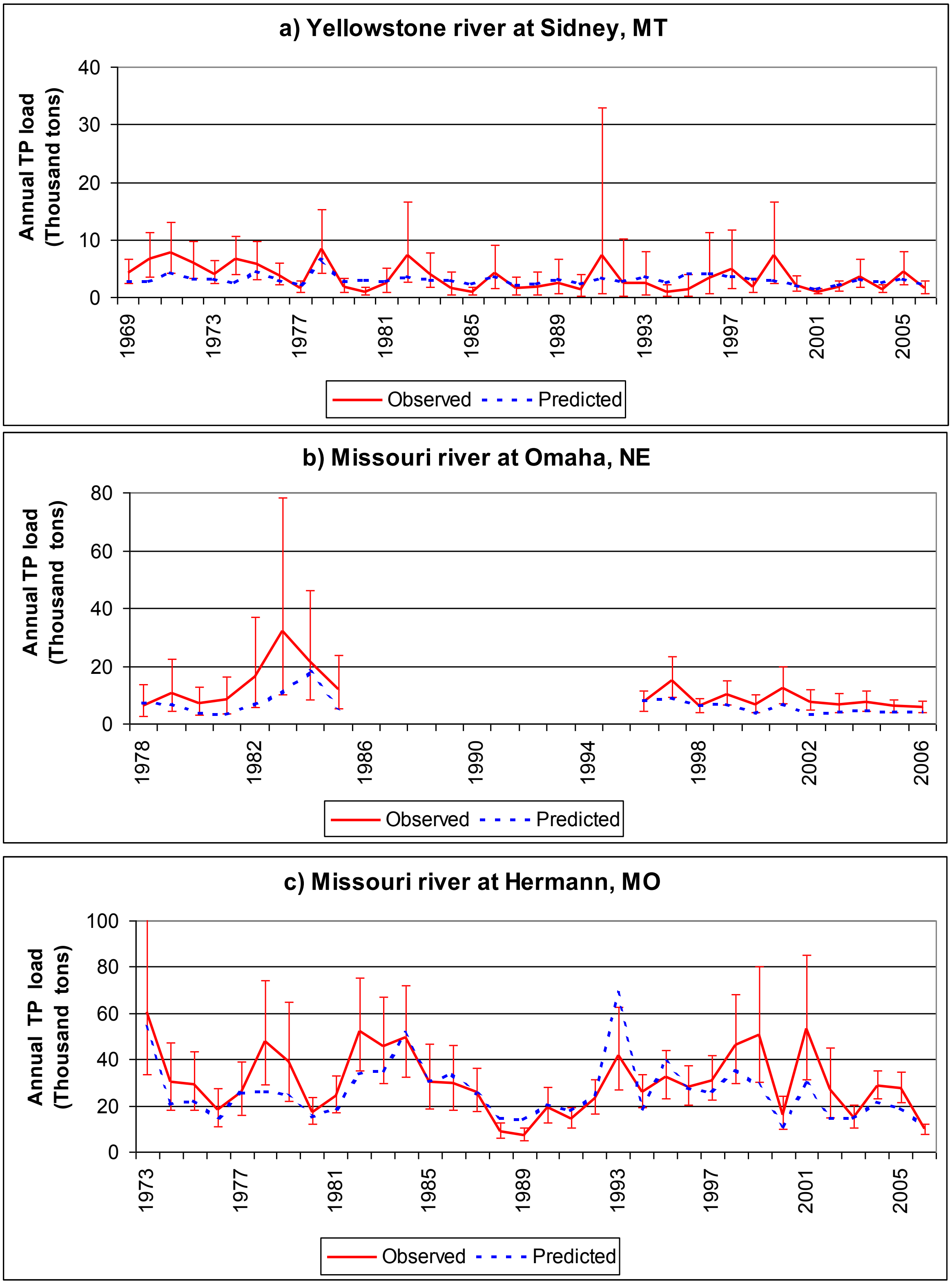


Figure 7-13 Average annual Ortho Phosphate (Ortho P) load for the Missouri River basin

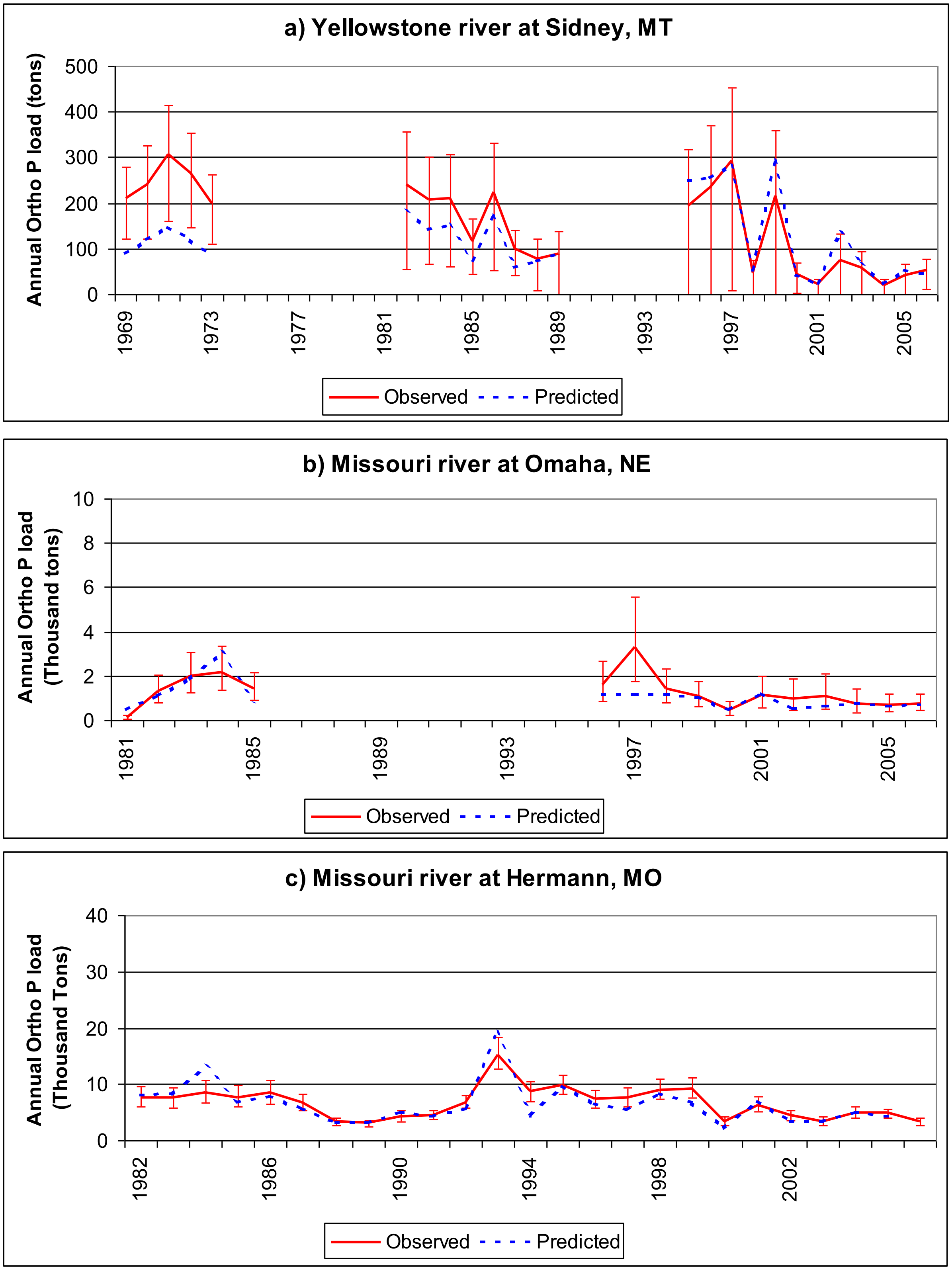


Table 7-6 Average annual Suspended Sediment load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Missouri River at Culbertson, MT	10060005	3,285,473	2,843,498
Yellowstone river at Sidney, MT	10100004	11,758,728	12,771,925
Missouri River at Bismark, ND	10130101	2,618,053	2,842,088
Missouri River at Yankston, SD	10170101	------	------
Platte river at Louisville, NE	10200202	7,892,677	10,438,963
Missouri River at Omaha, NE	10230006	17,301,084	20,365,540
Osage river at St Thomas, MO	10290111	------	------
Missouri River at Hermann, MO	10300200	39,944,211	43,115,954

Table 7-7a Average annual Nitrate and Nitrite Nitrogen load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Missouri River at Culbertson, MT	10060005	1,346	676
Yellowstone river at Sidney, MT	10100004	4,640	3,478
Missouri River at Bismark, ND	10130101	2,999	2,557
Missouri River at Yankston, SD	10170101	2,578	1,635
Platte river at Louisville, NE	10200202	19,267	14,503
Missouri River at Omaha, NE	10230006	28,103	39,535
Osage river at St Thomas, MO	10290111	5,718	4,742
Missouri River at Hermann, MO	10300200	120,638	117,965

Table 7-7b Average annual total Kjeldahl Nitrogen load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Missouri River at Culbertson, MT	10060005	4,905	5,465
Yellowstone river at Sidney, MT	10100004	8,416	10,027
Missouri River at Bismark, ND	10130101	------	------
Missouri River at Yankston, SD	10170101	5,356	5,417
Platte river at Louisville, NE	10200202	26,480	17,887
Missouri River at Omaha, NE	10230006	28,307	38,759
Osage river at St Thomas, MO	10290111	1,963	6,194
Missouri River at Hermann, MO	10300200	119,837	121,439

Table 7-7c Average annual Ammonia Nitrogen load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Missouri River at Culbertson, MT	10060005	1,214	658
Yellowstone river at Sidney, MT	10100004	885	685
Missouri River at Bismark, ND	10130101	------	------
Missouri River at Yankston, SD	10170101	793	340
Platte river at Louisville, NE	10200202	5,242	1,117
Missouri River at Omaha, NE	10230006	1,906	2,775
Osage river at St Thomas, MO	10290111	346	609
Missouri River at Hermann, MO	10300200	5,184	5,375

Table 7-7d Average annual Total Nitrogen load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Missouri River at Culbertson, MT	10060005	6,251	6,142
Yellowstone river at Sidney, MT	10100004	13,055	13,505
Missouri River at Bismark, ND	10130101	------	------
Missouri River at Yankston, SD	10170101	7,934	7,052
Platte river at Louisville, NE	10200202	45,747	32,390
Missouri River at Omaha, NE	10230006	56,410	78,294
Osage river at St Thomas, MO	10290111	7,680	10,935
Missouri River at Hermann, MO	10300200	240,474	239,404

Table 7-8a Average annual Total Phosphorus load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Missouri River at Culbertson, MT	10060005	1,393	1,273
Yellowstone river at Sidney, MT	10100004	2,942	3,476
Missouri River at Bismark, ND	10130101	993	762
Missouri River at Yankston, SD	10170101	461	444
Platte river at Louisville, NE	10200202	5,564	4,583
Missouri River at Omaha, NE	10230006	6,290	10,774
Osage river at St Thomas, MO	10290111	949	653
Missouri River at Hermann, MO	10300200	25,925	30,247

Table 7-8b Average annual Ortho Phosphate load at selected gauging stations

River-Gauging station-Location	Reach (HUC)	Predicted (tons)	Observed (tons)
Missouri River at Culbertson, MT	10060005	90	115
Yellowstone river at Sidney, MT	10100004	219	151
Missouri River at Bismark, ND	10130101	229	357
Missouri River at Yankston, SD	10170101	76	42
Platte river at Louisville, NE	10200202	1,939	1,423
Missouri River at Omaha, NE	10230006	1,029	1,270
Osage river at St Thomas, MO	10290111	297	284
Missouri River at Hermann, MO	10300200	6,324	6,640

Chapter 8 describes results of calibration and validation of CEAP-HUMUS model setup for the Arkansas-White-Red River Basin. More details on procedures used in the calibration-validation process are presented in Chapter 1.

(Status: Forthcoming!!)

Chapter 9 describes results of calibration and validation of CEAP-HUMUS model setup for the Lower Mississippi River Basin. More details on procedures used in the calibration-validation process are presented in Chapter 1.

(Status: Forthcoming!!)